COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH (CILER)

ANNUAL REPORT

NA17RJ1225 — Year Four
July 1, 2004 to June 30, 2005

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Cooperative Institute for Limnology and Ecosystems Research
CILER

Annual Report for NA17RJ1225
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The Cooperative Institute for Limnology and Ecosystems Research - Overview

The Cooperative Institute for Limnology and Ecosystems Research (CILER) is a NOAA Cooperative Institute that facilitates collaborative research between NOAA's Great Lakes Environmental Research Lab (GLERL), the University of Michigan, and other universities and not-for-profit research institutes. One of the primary missions of CILER is to improve the effectiveness of NOAA-sponsored research on freshwater, coastal, and estuarine areas with particular emphasis on the Great Lakes. Established in 1989, CILER is the only joint institute with primary research responsibilities in freshwater systems. In addition to its research activities, CILER is also strongly involved in educational activities and initiatives by hosting the Great Lakes National Ocean Sciences Bowl in addition to providing summer research opportunities for high school, undergraduate, and graduate students.

CILER's research is categorized based on five different science themes: 1) climate and large lake dynamics; 2) coastal and nearshore processes; 3) large lake ecosystem structure and function; 4) remote sensing of large lakes and coastal ocean dynamics; and 5) marine environmental engineering. Research conducted under the climate and large lake dynamics theme seeks to address the role of anthropogenic activities in affecting larger-scale regional and global climatic conditions. Research in the second theme, coastal and nearshore processes, is directed primarily at elucidating the linkages between the physical, chemical, and biological conditions in nearshore regions with a primary focus on studies of sediment-water exchange and sediment transport in the Great Lakes and other ecosystems. More recent initiatives in this theme involve developing models to help forecast bacteria levels and water quality

in the Great Lakes, with particular applications for predicting beach closings. The large lake ecosystem structure and function theme supports projects concerning Great Lakes ecology, including the cycling of critical materials, linkages between the physico-chemical environment and lake biota, and the ecological consequences of aquatic nonindigenous species. The fourth theme, remote sensing of large lakes and coastal ocean dynamics, includes projects that develop new sensing technologies to help monitor and study freshwater and coastal environments. Finally, research conducted under the marine environmental engineering theme focuses on assessments of environmental risks posed by vectors for nonindigenous aquatic species and contaminated sediments in addition to supporting novel engineering designs that improve our understanding of the aquatic environment. Many of the current and future research efforts in all of the research themes focus on improving the scientific basis for generating Great Lakes ecosystem forecasts and for achieving Great Lakes restoration goals.

CILER's Mission

The overarching missions of CILER are best described by the four objectives put forth in the original Memorandum of Understanding that created CILER. They are as follows:

1). To improve the effectiveness of NOAA's sponsored research on freshwater, coastal, and estuarine areas with particular emphasis on Great Lakes issues by fostering collaboration between GLERL and other federal, international, state, and local agencies and the Great Lakes academic research community.

2). To serve as a focal point for the interaction between NOAA and the Great Lakes research community.

3). To improve the effectiveness of graduate level education and expand the scientific research experiences available to graduate students.

4). To provide expanded training opportunities in aquatic environmental research for both NOAA and academic community scientific and technical personnel.

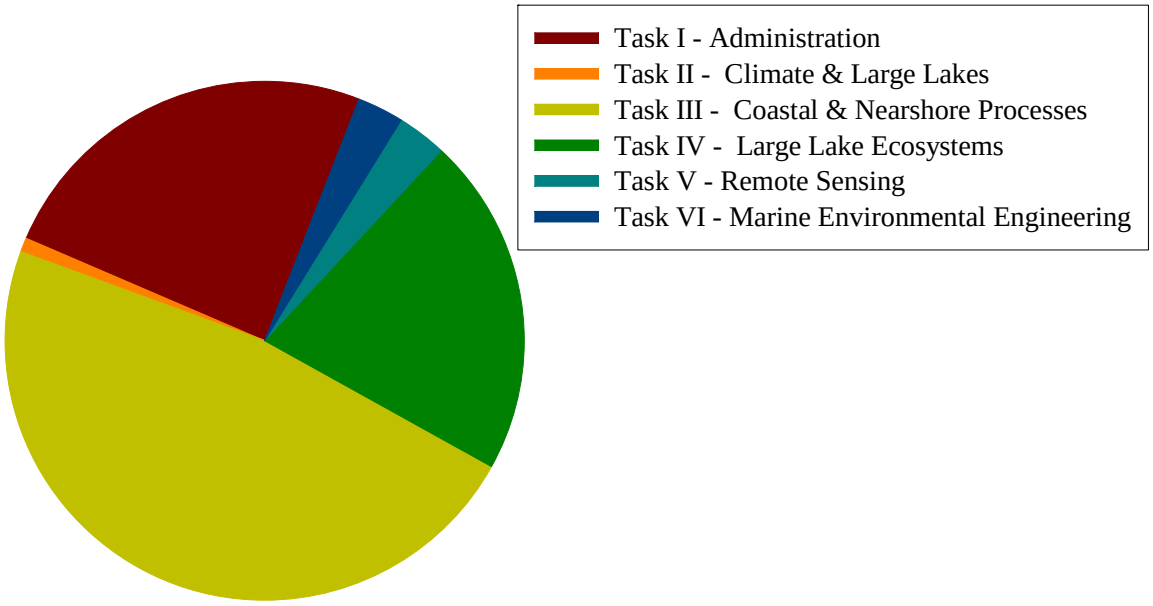
Within the context of this mission, CILER's scientific vision evolves with the needs of the region and with NOAA's evolving directions.

Summary of Research Activities

This report details activities for the fourth year of our current cooperative agreement and covers the period from July 1, 2004 to June 30, 2005. During this period CILER administered approximately 40 projects of which 35 supported activities within our five research themes and 5 supported our Task I visiting fellows and science enhancement program. All of the Task I projects are a continuation of ongoing activities, except for one new project to fund an outreach coordinator for the new Center for Excellence in Great Lakes and Human Health (see Administrative Activities section for more details).

The total funding level this fourth year of the cooperative agreement activity was $2,357,149 (Figure 1). This represents a large increase in funding over the previous three years. Much of this increase is attributed to funds associated with the new NOAA Center for Excellence in Great Lakes and Human Health. This has contributed several new projects to Tasks I, III, and IV.

Figure 1. Funding distribution for CILER by Task number from 07/01/04 to 06/30/05.



We currently have active research projects in all five of our thematic areas. Funding for Task IV (Large Lake Ecosystem Structure and Function) continues to support the largest number of projects; however Task III (Coastal and Nearshore Processes) has received the largest amount of grant dollars over this four year period. A large

increase in the funds for this task in the past fiscal year was associated with the influx of money to sponsor research that will support initiatives through the new Center for Excellence in Great Lakes and Human Health.

Table 1. Breakdown of funding by Task awarded to CILER for the current Cooperative Agreement, NA17RJ1225 for the period July 2001 through the current funding period (06/30/05).

Task	Research Theme	# Projects	Funding ($)	% Funding
I	Administration and Research Enhancement	19	2,180,347	28
II	Climate and Large-Lake Dynamics	14	539,293	7
III	Coastal and Nearshore Processes	11	2,458,627	32
IV	Large Lake Ecosystem Structure / Function	29	1,774,060	23
V	Remote Sensing / Coastal Ocean Dynamics	3	405,845	5
VI	Marine Environmental Engineering	9	433,667	6
	TOTALS	85	7,791,839	

The majority of the projects sponsored by CILER this year continue to support NOAA's Strategic Goal number one: To Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management. For each research project, we have identified which of the NOAA strategic goals is supported and these designations are listed under each project title within the report.

The following are highlights of some of the accomplishments achieved in the different research themes.

Climate and Large Lake Dynamics

- A 2 km numerical hydrodynamic model has been developed for Lake Erie which will be coupled with a dynamic ice model to help advance both the Great Lakes Coastal Forecasting System and to improve wintertime and ice forecasts for this area.
- The Lake Erie hydrodynamic model has been used to simulate phosphorous loadings in the lake with reasonable results. This project provides critical support for the new research initiative on Lake Erie led by the Great Lakes Environmental Research Lab.
- Sampling of mercury deposition continued in the Lake Champlain Basin. Current results indicate that mercury deposition associated with precipitation

events are strongly affected by the season, type of precipitation event, and meteorological transport history.

Coastal and Nearshore Processes

- The NOAA Center for Excellence in Great Lakes and Human Health (CEGLHH) was established at GLERL in 2004. This Center has provided several grants to CILER for this fiscal period. The focus of the center is on coordinating and conducting research to forecast water quality changes in the Great Lakes that have direct relevance to human health.
- Hydrodynamic simulations generated from research stemming from CEGLHH have been used to model sewage overflows in Milwaukee, Wisconsin that occurred in May 2004. These results demonstrate that based on Lake Michigan circulation, water from the Milwaukee River could not have been transported to Chicago and thus did not constitute a health risk to this particular urban population

Large Lake Ecosystem Structure and Function

- The results from field collections coupled with laboratory observations suggest that predation by the invasive zooplankton, *Bythotrephes longimanus*, on the invasive zooplankton, *Cercopagis pengoi*, probably controls the distribution of this latter species. This further demonstrates the complex interactions between invasive aquatic organisms within the Great Lakes.
- Alewives in the Great Lakes appear to demonstrate a strong preference for *Bythotrephes* over *Cercopagis*, which has implications for the population dynamics of both invasive zooplankters in lakes where there is heavy predation by alewives.
- Laboratory studies of behavioral responses of zooplankton to the invasive predatory cladoceran *Bythotrephes* suggest that several species of native cladocerans and copepod species dramatically alter their behavior in the presence of this predator. This has potential implications for condition and growth of these native zooplankton and supports the "trait-mediated interaction" hypothesis describing net effects of predators on prey species.
- A Multi-component Damage Assessment Model was developed to help simulate and explain cumulative damage of multiple toxicants in an invertebrate model (the benthic amphipod, *Diporeia*). This has application for

developing water and sediment quality guidelines for exposures to multiple contaminants.

- A large field project on Lake Erie began in the summer of 2005 to investigate the role of hypoxia and impact of nonindigenous species on the trophic web in this lake. Extensive field data have been collected on dissolved oxygen, water temperature, fish diets, fish distribution, and prey abundance and distributions.
- Work on Harmful Algal Blooms in Saginaw Bay have revealed that the community consists primarily of *Microcystis* spp. and *Anacystis* sp., while community composition in Lake Erie was dominated by *Microcystis*.

Remote Sensing of Large Lakes and Coastal Ocean Dynamics

- The GLERL website has been improved in order to allow for greater CoastWatch data availability including the ability to receive and handle HDF file formats and the installation of a dedicated web server. This should improve access and use of data housed by CoastWatch and improve userability of the website and associated data.

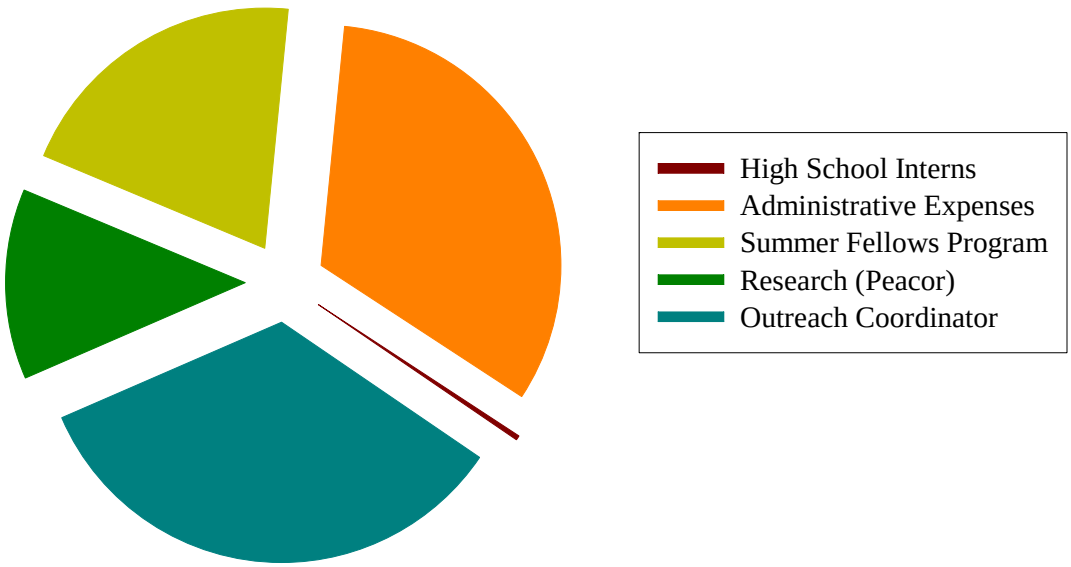
Marine Environmental Engineering

- A final report was completed on the physical, chemical, and biological characterization of overseas unballasted vessels (ie., no-ballast-on-board, NOBOBs) trading in the Great Lakes. The results indicate that a variety of viable organisms and resting stages are carried by unballasted overseas vessels entering Great Lakes waters. There was a large amount of variability in the type and amount of viable organisms, which did not appear to vary in a systematic way with vessel characteristics (such as vessel size, vessel transit time, last time since cleaning, etc.).
- A survey was conducted of NOBOBs, yielding additional information about these vessels. The data indicate that approximately 90% of overseas vessels actually enter the St. Lawrence Seaway as NOBOBs. This is consistent with results from other studies and demonstrates that the vast majority of overseas vessels entering the Great Lakes are declared NOBOBs and thus currently unregulated.

Administrative Activities

Administrative activities associated with CILER are contained within Task I. Actual administrative expenses help cover a portion of the work of the Director and Assistant Director and the full-time appointment of an Administrative Assistant. The enhancement activities that were conducted under Task I during 2004-2005 include our postdoctoral fellows program, our summer high school intern program, our Great Lakes Student Summer Fellows program for undergraduates and graduates, and a Great Lakes seminar series run in collaboration with NOAA-GLERL. All of these programs support part of CILER's mission by providing opportunities for students and post-docs to participate in the Institutes research programs, and to provide a focal point for interactions between NOAA and the Great Lakes research community. Finally, another major administrative responsibility for CILER staff during this fiscal year was coordinating and organizing a major program review that occurred June 1-2, 2005. Preparation for this event required large time commitments from the entire administrative and research staff. The results of this review were made available in late September and provided a validation of CILER's programs overall in addition to important suggestions for strengthening this joint, cooperative institute.

Figure 2. Funding distribution of categories in Administrative Funds (Task I) from 07/01/04 to 06/30/05.



New CILER Initiatives

CILER has been involved in several new initiatives that should help advance the current missions of the institute in addition to strengthening the program overall. The first initiative is a new CILER Research Investigator Program. This program has been developed to further foster collaborative research within the Great Lakes region and to continue to strengthen Great Lakes Research at NOAA-GLERL and the University of Michigan. To date, this program has brought in one new Research Investigator (Tomas Höök) to work on fish ecology issues in the Great Lakes. In addition, three new hires are under consideration for this program with expertise in areas ranging from Ecological Toxicology to Statistical Forecasting and Modeling.

The second major CILER initiative has been working on a plan for a Great Lakes Research Facility located at the University of Michigan that would co-house researchers from GLERL, CILER, the Institute for Fisheries Research (State of Michigan), the Great Lakes Fisheries Commission, the Great Lakes Commission, Great Lakes faculty and researchers from the School of Natural Resources and Environment (University of Michigan), and possibly the USGS-Great Lakes Science Center. Although the concepts and potential designs for this building have been in the works for several years, it was only the past year that significant progress has been made on getting the building plans together and generating concrete design plans along with cost estimates. Although final decisions still need to be made, it currently appears as though this Great Lakes Facility will become a reality over the next three to four years. Significant administrative work has gone into to identifying CILER space needs for the building and helping coordinate building design and partners.

Council of Fellows/Executive Board

The Executive Board for CILER consists of the following 5 members:

Fawwaz T. Ulaby, Vice President for Research, University of Michigan
J. Ian Gray, Vice President for Research, Michigan State University
Rosina Bierbaum, Dean, School of Natural Resources & Environment, UM
Louisa Koch, OAR Deputy Administrative Assistant
Stephen B. Brandt, Director, Great Lakes Environmental Research Lab.

The last meeting of the CILER Executive Board was held on March 15, 2005.

The Council of Fellows for CILER consists of the following 9 scientists:

Jim Diana, Professor and Associated Dean, SNRE

Brian Eadie, Scientist, NOAA-GLERL
Val Klump, University of Wisconsin - Milwaukee
Peter F. Landrum, Scientist, NOAA-GLERL
David Reid, Scientist, NOAA-GLERL
Jeffrey Reutter, The Ohio State University, Ohio Sea Grant Program
David Schwab, Scientist, NOAA-GLERL
Bill Taylor, Michigan State University, Michigan Sea Grant Program
Henry Vanderploeg, Scientist, NOAA-GLERL

The last meeting of the CILER Council of Fellows was on April 14th, 2005.

ADMINISTRATION AND RESEARCH ENHANCEMENT

CA4/I-02: PARTNERS-FOR-EXCELLENCE SUMMER HIGH SCHOOL INTERN PROGRAM

Principal Investigator: Thomas F. Nalepa, Great Lakes Environmental Research Laboratory

As a continuing effort to provide research experiences for high school students, CILER again partnered with the Science Department of the Ann Arbor Public Schools and the Great Lakes Environmental Research Laboratory to sponsor two students for the summer of 2005:

Vinayak Nikam	Huron High School	Mentor: Margaret Lansing
Evie Covés-Datson	Pioneer High School	Mentor: Tom Nalepa

To apply for this program, the applicants submit an essay and attain a letter of recommendation from their science teacher. Qualified students are then selected to participate in the summer research experience. For this summer's program, Ms. Covés-Datson gained experience processing benthic samples from different sites in the Great Lakes and learned to identify the different taxa present in these samples. During his summer research, Mr. Nikam helped manage the database for the International Field Years on Lake Erie and assisted with preparing sediment samples for organic carbon analysis for a project monitoring PCB concentrations in Great Lakes sediments. This program was highlighted in the NOAA report, August 2005, Vol. XIV no. 8 (available at http://www.publicaffairs.noaa.gov/nr/).

CA4/I-11: GREAT LAKES SUMMER STUDENT FELLOWSHIP PROGRAM

Principal Investigators: Donald Scavia, University of Michigan and Stephen B. Brandt, Great Lakes Environmental Research Laboratory

The Cooperative Institute for Limnology and Ecosystems Research and the Great Lakes Environmental Research Laboratory implemented the Great Lakes Summer Student Fellowship Program in 1998. To date, more than 120 student fellows have been supported by this program.

For summer 2005, 28 student fellow positions were selected, with preference given to currently enrolled undergraduate students or those who have recently graduated. Graduate applicants were also considered. Each student fellow worked under the mentorship of an individual scientist or professional in a broad range of fields.

Student Fellow	Academic Institution	Fellowship Field
Courtney Anegon	Knox College	Chemist/Biochemist
Kathleen Bailey	University of Michigan	Aquatic Ecologist
Cassandra Beatty	University of Southern California	Aquatic Ecologist
Christine Bergeon	University of Michigan	Aquatic Ecologist
Samantha Bickel	Carthage College	Aquatic Ecologist
Peter Bieniek	Valparaiso University	Atmospheric Analyst
Lu Chen	Massachusetts Institute of Technology	Aquatic Biologist
Josh Cowden	Michigan Technological Institute	GIS/Web Programmer
Melissa Cuke	Queens University	Oceanography Technician
Meghan Eschbaugh	Michigan Technological Institute	Ecologist
Deanna Frankowski	Ripon College	Aquatic Ecologist
Sheri Goings	Michigan State University	Computer Programmer
Steven Good	Michigan Technological Institute	Computer Programmer
Hal Gunder	University of Michigan	Aquatic Ecologist
Gregory Jacobs	Alma College	Aquatic Biologist
Jesse Kipp	University of Wisconsin – Milwaukee	Electronic Engineer
Katie Krieger	Michigan State University	Aquatic Ecologist
Katie Marko	University of Michigan	Researcher
Calvin Mires	East Carolina University	Maritime Historian
Naftali Mwaniki	Ferris State University	African Climate Technician
Sri Muthyala	Eastern Michigan University	Remote Sensing/GIS Tech.
Bradley Robinson	Grand Valley State University	Aquatic Ecologist
Sean Sisler	University of Minnesota	Aquatic Ecologist
Heather Smith	Michigan State University	Aquatic Ecologist
Shannon Wetzel	Salish Kootena College	EEO Summer Fellow
Natalie White	Northern Michigan University	Aquatic Ecologist
Kristin Woycheese	Carthage College	Ecologist
Sarah Van't Hof	Michigan State University	Communications & Outreach

All student fellows were University of Michigan guest students working with either a GLERL or CILER mentor primarily in Ann Arbor, Michigan. Five fellows worked in Muskegon, Michigan, one fellow worked in Alpena, Michigan and two fellows worked in Houghton, Michigan. The fellows worked on projects ranging from field work associated with hypoxia and harmful algal blooms events in Lake Erie to communications and outreach efforts at GLERL. This year's cohort of fellows was

asked to provide a written report of their research experience. In addition, for the first time this year, summer fellows residing in Ann Arbor were requested to give oral presentations of their work. An environmental careers seminar was also organized for the summer fellows in Ann Arbor, which included an invited panel of professionals from different sectors who discussed job opportunities in the environmental sciences.

Official evaluations of the program were solicited from both student fellows and mentors. Overall the program received high accolades from both student fellows and mentors. Student fellows expressed appreciation of the direct research experiences they gained during their fellowship and enjoyed the knowledge and skills they gained by working with their mentors. This program continues to be a major success story for both CILER and GLERL.

CA4/I-12: GREAT LAKES SEMINAR SERIES

Principal Investigators: David F. Reid, Great Lakes Environmental Research Laboratory; Rochelle Sturtevant, Michigan Sea Grant College Program and Thomas H. Johengen, University of Michigan

One of the most productive means to enhance research collaborations between NOAA and the academic research community is to facilitate and encourage communication and networking. CILER fosters this opportunity through a seminar series of invited speakers and targeted topics. CILER has co-sponsored the Great Lakes Seminar Series since July 2001. Speakers are solicited in a broad range of disciplines encompassing all of our research theme areas. In FY 2005, 24 speakers presented seminars.

Seminar Presentations

Padera, C. (PBS&J and Program Manager, Everglades Partners Joint Venture), Hinsley, W. (PBS&J and Program Manager, Louisiana Coastal Area Ecosystem Restoration Project), and Sinha, S. (Water Resources, Environmental Consulting & Technology, Inc.). "Managing Everglades restoration project: lessons learned for Great Lakes restoration." June 2, 2005.

Hicks, R.E. (University of Minnesota – Duluth). "Revealing sources of *E. coli* and *Archaea* in the Great Lakes." May 23, 2005.

Hawley, N. (GLERL). "Sediment transport studies in the Great Lakes." May 19, 2005.

Lisle, J. (U.S. Geological Survey). "Microbial indicators and environmental health: from Antarctica to Florida's coral reefs." May 13, 2005.

Chu, X. (Grand Valley State University). "Development of Windows-based hydrologic and environmental modeling systems." May 5, 2005.

Smoot, J. (University of Washington). "Fatty acids, functional groups, phages, and phylogenetics: Selected insights in microbial community and population analyses." May 4, 2005.

Beletsky, D. (CILER/University of Michigan). "Modeling larval fish transport and growth in Lake Michigan." April 21, 2005.

Ruetz, C.R. (Grand Valley State University). "Fish monitoring in Muskegon Lake: Evaluating gear bias and ecological impacts of round gobies." April 7, 2005.

Rediske, R.R. (Grand Valley State University). "The assessment of contaminated sediment in drowned river mouth lakes." March 29, 2005.

Lofgren, B. (GLERL). "Climate modeling on the Great Lakes that is both wrong and useful." March 17, 2005.

Biddanda, B.A. (Grand Valley State University). "Exploration of a submerged sinkhole ecosystem in Lake Huron." February 24, 2005.

Vanderploeg, H. (GLERL). "Anatomy of the recurrent coastal plume in Lake Michigan: interactions among turbulence, suspended sediments, light, nutrients, and plankton." February 17, 2005.

Restrepo, P. (National Weather Service, NOAA). "Overview of the NOAA Hydrology Program and the Office of Hydrologic Development research activities." February 14, 2005.

Mason, D. (GLERL). "Numerical and physiological responses of fish to reef habitat in marine coastal ecosystems." January 20, 2005.

Reid, D. (GLERL). "Modeling of ballast water flow dynamics in ballast tanks during ballast water exchange." December 16, 2004.

Pozdnyakov, D.V. (Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russia). "A new operational bio-optical algorithm for the assessment of water quality in the Great Lakes: Algorithm validation and application for studying seasonal and inter-annual variations in specific phenomena inherent in Lake Michigan from SeaWiFS and MODIS images." December 9, 2004.

Schwab, D. (GLERL). "An examination of winds and waves on Lake Superior associated with the wreck of the Edmund Fitzgerald on November 10, 1975." November 18, 2004.

Lamon, E.C. III (Louisiana State University). "Bayesian methods in ecological forecasting." November 10, 2004.

Varanasi, U. (NOAA Northwest Fisheries Science Center). "The Northwest Fisheries Science Center and NOAA's West Coast Center for Oceans and Human Health." November 9, 2004.

Vasiloff, S. (Hydrometeorological Applications), and Howard, K. (NOAA National Severe Storms Laboratory). "A national testbed for hydrometerological development." November 3, 2004.

Rochford, P. (Spectral Sciences, Inc.). "A coupled bio-physical model of the California Current System." October 26, 2004.

Fahnenstiel, G. (GLERL). "Ramblings about algae in the Great Lakes." October 21, 2004.

Höök, T. (University of Michigan). "Habitat-mediated production and recruitment of young alewives in Lake Michigan." October 19, 2004.

Brandt, S. (GLERL). "Spatial modeling of fish growth rate and predator-prey interactions." September 16, 2004.

CA4/I-13: A COLLABORATIVE FACULTY POSITION WITH MICHIGAN STATE UNIVERSITY TO ENHANCE RESEARCH AND OUTREACH ACTIVITIES BETWEEN NOAA AND UNIVERSITIES THROUGHOUT THE GREAT LAKES BASIN.

Principal Investigators: Donald Scavia, University of Michigan; William Taylor, Michigan State University; and Stephen B. Brandt, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

A collaborative faculty position continues to be supported through CILER administrative activities. This position was conceived to help coordinate and strength research, teaching, and outreach programs between NOAA and Michigan State University by emphasizing the development, testing, and use of Great Lakes aquatic system models, with additional research in marine coastal and estuarine systems.

This collaborative faculty position is currently filled by Dr. Scott Peacor, an ecosystem modeler. Dr. Peacor's research and teaching are centered on understanding species interactions, distributions and dynamics. During his 5-year tenure in this position, Dr. Peacor has built a research program that elucidates mechanisms that determine the structure and dynamics of ecological communities, and in particular the Great Lakes ecosystems. He is currently integrating laboratory,

field, conventional modeling, and cutting edge theoretical approaches to elucidate concepts that are of general importance to all ecosystems and of practical import to society. While Peacor's research has a common theme, he has embarked on several complimentary lines of research.

Some of Dr. Peacor's research highlights are as follows

Accomplishments

- *Phenotypic plasticity and consequent trait-mediated indirect interactions: conventional theory* - developing theory that suggests that the consequences of phenotypic plasticity and consequent trait-mediated interactions, such as response to species fitness and community structure, are substantial. This has resulted in several publications to date and development of several national and international collaborations.
- *Invasive predator cladocerans in the Great Lakes: effects of trait-mediated effects* – development of a research program to support the hypothesis that a predatory invertebrate, the spiny water flea, is posing a potential serious threat to Great Lakes fisheries by disrupting the food web.
- *DOVE: Digital Organisms in a Virtual Ecosystem* – development of a novel method for modeling properties of ecological systems (e.g. phenotypic plasticity and evolution) which are difficult to evaluate with traditional approaches. To this end, Dr. Peacor has created a computational system that uses evolutionary algorithms to simulate natural selection and allow species to evolve and solve the complex problem of persistence in the presence of multiple tradeoffs.

Publications

Peacor, S. D., R. L. Riolo, and M. Pascual. 2005. Phenotypic plasticity and species coexistence: modeling food webs as complex adaptive systems. In Press *In* M. Pascual and J. A. Dunne, editors. Food Webs as Complex Adaptive Networks: Linking Structure to Dynamics. Oxford University Press, Oxford.

Peacor, S. D, K. Pangle, and H. Vanderploeg. 2005. Behavioral response of Lake Michigan *Daphnia mendotae* to *Mysis relicta*. J. Great Lakes Res. In Press.

Peacor, S. D. and E. E. Werner. 2004. How dependent are species-pair interaction strengths on other species in the food web? Ecology 85: 2754-2763.

Peacor, S. D. and E. E. Werner. 2004. Context dependence of non-lethal predator effects on prey growth. Israel Journal of Zoology 50:139-167. (Invited article for special issue)

Grants

2004-2007	EPA/ECOHAB: $454,779 "Complex interactions between harmful phytoplankton and grazers: variation in zebra mussel effects across nutrient gradients"
2004-2005	Michigan State University Intramural Research Grants Program: $50,000 "A computational system (DOVE) to study phenotypic plasticity and its effects on food webs"
2004-2006	Great Lakes Fishery Commission: $173,657 "Fish Recruitment Disruption Due to Invasive Predator Cladocerans: Density and Behaviorally Mediated Effects"

CA4/I-14: Outreach and Education Coordination for the NOAA Center for Excellence in Great Lakes and Human Health

This position will be hired through Michigan State University to assist with the Center for Excellence in Great Lakes and Human Health. The position currently remains vacant and thus there has been no activity to date on this account.

CLIMATE AND LARGE-LAKE DYNAMICS

Research conducted by CILER under the theme of Climate and Large Lake Dynamics focused originally on climatic change, but has been broadened to include research into the interaction of large lakes and the atmosphere and their combined influence on physical processes. Included in this task are activities such as the study of heat flux into and out of large lakes, wind forecasts, hydrodynamic forecasting and coupled hydrosphere-atmosphere models.

CA4/II-02: MODELING ICE THERMODYNAMICS AND TRANSPORT IN THE GREAT LAKES

Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

Ice cover can cause significant changes in waves and winter circulation patterns in a large lake because it affects both momentum and heat transfer between the atmosphere and the water column. The first numerical model of ice transport in the Great Lakes was developed by Rumer *et al.*, 1981. It was based on Hibler's dynamic-thermodynamic sea-ice model Hibler, 1979, but used a very simple circulation model. The model showed some success when applied to Lake Erie. Another two-dimensional model for the Great Lakes was developed about the same time by Robert Grumbine at NCEP based on his work on ocean ice models. His model can be used for both short-term (days) and long-term (up to one week) predictions. Recently, Wang *et al.*, 1994 were able to simulate quite realistically the ice dynamics in Hudson Bay by applying Hibler's model coupled with the three-dimensional hydrodynamic model of Blumberg and Mellor, 1987. The Mellor and Blumberg Princeton Ocean Model was quite successful in describing winter circulation in Lake Michigan in two very mild winters: 1982-1983, and 1994-1995, when the lake was essentially ice-free (Beletsky *et al.*, 1997).

Momentum transfer is generally reduced by the presence of ice. Measurements of ice movement in Lake Erie (Campbell *et al.*, 1987) by means of drifting buoys still represent the most significant source of information on wind-induced ice transport in the Great Lakes. In particular, they reported the mean observed speed of the buoys in ice is about 8 cm/s, half the mean speed observed in open water. The effect of partial ice cover on wave generation and propagation is unknown. In this

proposal, we are planning to incorporate these effects to have a coupled dynamic ice-circulation model for the Great Lakes, based on the Great Lakes version of the Princeton Ocean model and the Mellor-Hakkinen ice dynamic code. The code will be tested using Assel's extensive Great Lakes ice climatology data base and atmospheric forcing functions from GLCFS.

The objective of this project is to incorporate ice effects on hydrodynamic processes in the Great Lakes. We will use a transfer function approach to refine predictions of existing hydrodynamic models and also adapt the coupled ice dynamic model of Mellor and Hakkinen (Mellor and Kantha, 1989: Mellor and Hakkinen, 1995: Hakkinen and Mellor, 1992) to the Great Lakes and test it under a variety of typical winter conditions. The Great Lakes version of the Princeton Ocean model will be used as the basis for the hydrodynamics portion of the code. If the tests are successful, the code will be incorporated into the Great Lakes Coastal Forecasting System in order to improve wintertime GLCFS forecasts as well as to produce operational Great Lakes ice forecasts.

Accomplishments

- A 2 km numerical hydrodynamic model was developed for Lake Erie. This model is being coupled with dynamic ice model of Mellor and Hakkinen.
- In addition, some simple modifications were made to operational wave and circulation models for all five lakes to incorporate ice effects on hydrodynamic processes. Bi-weekly ice charts from the National Ice Center are used as masks to limit the momentum input to wave and circulation models in ice-covered regions. Waves propagating into ice-covered regions will be attenuated proportionally to ice cover.
- Some preliminary tests in Lake Erie show considerable improvement in the ability of the hydrodynamic model to simulate water level fluctuations at Buffalo and Toledo during periods of partial ice cover on the lake.

CA4/II-04: Final Phase of the Lagrangian Drifters Pilot Program

Principal Investigator: Thomas O. Manley, Middlebury College

NOAA Strategic Goal 1

Overview and Objectives

Primary hydrodynamics of the Main Lake (of Lake Champlain) are governed by the dynamic internal seiche with a period of ~4.5 days. Linear, non-linear and extremely

non-linear modes (in the form of surges and gravity currents) have been proven to exist within the Main Lake. Unfortunately, mean circulation has been statistically futile due to the very high variance coupled with a very low mean flow at any of the previous locations where currents have been monitored. Lagrangian information not biased with surface tethered monitoring devices were required to help solve this problem and it was this requirement that created the lagrangian drifters pilot program. Over the past several years of testing and improvement of the system, some of the drifters have shown rather unexpected movement out of the central basin of the lake while others have shown confined trajectories within specific regions. Stability of the drifters have always been of concern in that they need to be stable to with a few feet of their target depth. In highly stratified regions, this is indeed the case however, in the epilimnion or hypolimnion, the drifter can oscillate well over 30 m while attempting to reach its planned depth.

The final phase of the lagrangian drifters program was to implement a final observational program of subsurface neutrally-buoyant drifters in the Main Lake of Lake Champlain. Eight underwater sound sources were deployed and four second-generation drifters were used in eight different tracking experiments to finally show the feasibility of an acoustically tracked system in a shallow lake. Drifters were to be released at various depths and locations in the lake for time periods of up to 2 weeks in an effort to better define some of the aspects of mean circulation dynamics of the various layers (epilimnion, metalimnion, and hypolimnion) of the Main Lake. Pierre Tiller of Seascan (Falmouth, MA), Jean Claude Gascard (LODYC, Paris), Ken Hunkins (LDEO, Columbia Univ., NY), Mike McCormick (GLERL, MI) and Tom Manley (Middlebury College) were the principle investigators in this program.

Accomplishments

- Data from the drifter program generated during this reporting period that led to the discovery of what was initially misclassified as a thermocline jet, wherein drifters were consistently and rapidly removed out of the central basin regardless of where they were placed with the lake. This misnomer of a thermocline jet was based solely on the starting and ending positions of the drifters that required some type of high-speed current to facilitate this movement. Final underwater trajectories however showed that the drifters located in the metalimnion actually moved to the western shoreline under southerly wind conditions and then were apparently caught into a coastal jet that then transported them to the south. During northerly winds, the opposite would occur and the drifter would move to the north out of the basin. As a result, the drifters have confirmed/shown the presence of a metalimnic cross-

circulation (across the axis of the lake in an east-west direction) that then creates/joins up with a coastal jet that provides the dominant motion to the south or north depending on wind direction. To the knowledge of this investigator, this cross-lake motion confined exclusively to the metalimnion has not been observed before. Other drifters placed above and below the metalimnion did not exhibit this motion. Vertical stability of the drifters were better than before in the unstratified portions of the water column, however, there is a belief that the addition of an external temperature sensor would provide more rapid information back to the software and therefore provide better stability. This will be carried out in the next program in the Inland Sea.

Publications

None to date.

Presentations

Manley, T. O., 2005. The Hidden Wave Beneath the Lake, invited evening community lecture series sponsored by The Nature Conservancy, Skeensborough, NY, 17 Feb.

Manley, T. O., 2005. Sound and Lake Champlain Research, invited talk at the ECHO, Burlington, VT, Feb.

Manley, T. O., 2005. Water Motion of Lake Champlain, invited lecture at the Water Seminar Series of the Rubenstein School of Natural Resources, Univ. of Vermont, 29 March.

Manley, T. O. and P. L. Manley, 2005. World and Local Research with Middlebury College Students, invited lecture at the South Street Presidential lecture series, Middlebury College, 6 May.

Manley, T.O., Gascard, J.C., And Tillier, P., 2005. Acoustically tracked Neutrally-buoyant Lagrangian Drifters in Lake Champlain – Results from the Last Year of the Feasibility Study, Intl, Assoc. Great Lakes Research Meeting, AnnArbor, MI., 24 May

Manley, P.L., Manley, T.O., Watson, M., And Gutierrez, J. 2005. Freshwater pockmarks in Lake Champlain, Intl, Assoc. Great Lakes Research Meeting, Ann Arbor, MI., 24 May

CA4/II-05: Atmospheric Mercury Deposition in Vermont – Sources and Long-Term Trends

Principal Investigators: Deane Wang, University of Vermont and Gerald Keeler, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

The University of Michigan Air Quality Laboratory, in collaboration with the University of Vermont, and the Vermont Monitoring Cooperative, initiated atmospheric mercury and mercury cycling research at the Proctor Maple Research Center in Underhill, Vermont in 1992. Sponsored by EPA and NOAA, the station began an event-base sampling program for mercury in wet precipitation. Collecting rain and snowfall by storm event, rather than on a fixed sampling schedule, allows one to relate mercury concentration patterns in individual storms to air mass history by calculating back trajectories.

The primary objectives of this project were to:

- complete analyses of event-based precipitation samples and bring historical records up to date.
- continue year-round monitoring of atmospheric mercury in wet deposition and particulate phase in the Lake Champlain Basin (LCB)
- investigate long-term trends in mercury deposition over the last decade in the LCB
- determine major sources and atmospheric transport pathways for mercury into Vermont.

The funds awarded to this research project were used exclusively to complete these program objectives.

Accomplishments/Results

- Mercury concentrations from individual precipitation events at Underhill ranged from ~0.9 – 90 ng/l over an 11-year period (1/1/93 – 12/31/03), with a volume-weighted mean event concentration of 8.9 ng/l. Factors such as season, type of precipitation, and meteorological transport history strongly influenced mercury concentrations at Underhill, while precipitation amount only explained about 20% of the variation.
- Event mercury wet deposition varied from ~0.002 – 1.8 ng/m^2 over this 11-year period, with an average event wet deposition of 0.10 ng/m^2. Clear

monthly and seasonal t seasonal trends in total wet mercury deposition were found, with the highest values observed during spring and summer months and the lowest in winter months.

- Large deposition events (>0.4 ug/m^2) accounted for 20-60% of the monthly and 5-17% of the total annual mercury deposition at Underhill. Mercury levels at Underhill showed year to year variation without a clear upward or downward trend. The highest mercury deposition events at Underhill traveled to Vermont along west-southwest and southerly transport corridors.

Publications

Keeler, Gerald J., Gratz, Lynne E. and Al-Wali, Khalid. (2005). Long-term atmospheric mercury wet deposition at Underhill, Vermont. *Ecotoxicology*, 14, 71-83.

Miller, E.K., VanArsdale, A., Keeler, G.J., Chalmers, A., Poissant, L., Kamman, N., and Brulotte, R. (2005) Estimation and mapping of wet and dry mercury deposition across Northeastern North America. *Ecotoxicology* 14, 53-70

Presentations

Keeler, Gerald J. (2004), Long-term atmospheric mercury wet deposition at Underhill, Vermont. Presentation given at the Annual Meeting of the Vermont Monitoring Cooperative, Burlington, VT, October 8, 2004.

Collaborations

Over the past decade atmospheric sampling has continued at Underhill making this Vermont dataset the longest continuous record of event-based mercury deposition in the United States, and possibly the world. These data have been integrated into ecosystem cycling studies looking at snow melt, stream export, and forest cycling including throughfall and leaf litter flux measurements. Because of the high quality and temporal resolution of these data, and location in the Lake Champlain basin, estimates of atmospheric mercury deposition measurement derived from the measurements at Underhill have been and are being used by more than a dozen scientists investigating mercury in terrestrial and aquatic ecosystems. These programs have fostered a community of researchers including atmospheric scientists, hydrologists, limnologists, ecologists, and biochemists actively collaborating to study the impacts of mercury on Vermont's and New England's ecosystems. These scientists represent several universities including the University

of Vermont, Plattsburg State and St. Lawrence University, Dartmouth College, and University of Michigan, Vermont and New York Departments of Environmental Conservation, NOAA, US EPA, US Forest Service, the Vermont Monitoring Cooperative and at least one private environmental consulting company.

CA4/II-06: MONITORING METEOROLOGICAL CONDITIONS ON LAKE CHAMPLAIN – SUPPORT FOR THE COLCHESTER REEF METEOROLOGICAL STATION

Principal Investigators: Deane Wang, University of Vermont; Richard Furbush, University of Vermont; and Carl Waite, University of Vermont

NOAA Strategic Goal 3

Overview and Objectives

Since July 1996 the Vermont Monitoring Cooperative (VMC) has operated and maintained an automated meteorological station on the navigational light tower at Colchester Reef, to provide near real-time meteorological data for Lake Champlain to researchers, resource managers and the public. This effort has been supported by contributions from the Lake Champlain Research Consortium (LCRC), the VMC, UVM's School of Natural Resources (SNR), and the National Weather Service (NWS). Data from this station are widely accessed to support NOAA atmospheric and hydrodynamic modeling efforts, other environmental and ecological research, local and regional weather forecasting, and commercial and recreational users of Lake Champlain.

The meteorological station at Colchester Reef is important to a wide variety and increasing number of users in the Lake Champlain region. The LCRC identified the need for this station as a research priority under atmospheric processes (December, 1999). In addition, on-lake meteorology was identified as an important research and monitoring priority by the Lake Champlain Management Conference (Watzin 1992). Finally, as indicated in the LCRC research priorities, these data are also one of the NWS' s most popular and are considered invaluable for prediction purposes by the NWS (see attached letter of support (2000) from the NWS).

The objectives of this project are:

- To insure continuous operation of the meteorological station at Colchester Reef.
- To provide and archive continuous, high quality, near real-time, meteorological data from Lake Champlain.
- To summarize annual and inter-annual meteorological trends in these data.

Accomplishments

- Meteorological variables are being measured at both stations and include air temperature, relative humidity, wind speed and direction, barometric pressure, total solar irradiance, precipitation (non-freezing months) and water temperature measured at 87 feet msl. Data from both stations are saved as 15 minute averages (except for precipitation which is summed), automatically downloaded hourly (four 15 minute records), and immediately made available to the National Weather Service (NWS) and other users.
- All annual equipment calibrations for 2005 have been performed at the Colchester Reef station and will be completed at Diamond Island in the near future. These state-of-the-art automated monitoring stations provide high quality near real-time (1 hour delay) meteorological data to the NWS in Burlington, a variety of researchers and resource managers, and to the general public, including, boaters and other recreational users of Lake Champlain. The NWS in turn makes these data available to the public over the internet at: http://www.erh.noaa.gov/er/btv/html/lake2.shtml and over the NOAA weather radio.

Publications

The following Lake Champlain Research Consortium Monographs have used data from the Colchester Reef meteorological station.

Manley, T.O. Hydrodynamics of the South Main Lake and South Lake, Lake Champlain.

Manley, P.L., T.O. Manley, M.C. Watzin, and J. Gutierrez. Lakebed Pockmarks in Burlington Bay, Lake Champlain: I. Hydrodynamics and Implications of Origin.

Gao, N., N.G. Armatas, B. Puchalski, P.K. Hopke, and R.L. Poirot. A Preliminary Investigation into the Possible Emission Sources for Atmospheric Mercury Found in the Lake Champlain Basin.

Gao, N. A Mass Balance Assessment For Mercury In Lake Champlain. (in press)

CA4/II-07: Monitoring Meteorological Conditions on Southern Lake Champlain – Establishment and Operation of a New Meteorological Station at Diamond Island

Principal Investigators: Deane Wang, University of Vermont; Richard Furbush, University of Vermont; and Carl Waite, University of Vermont

NOAA Strategic Goal 1

Overview and Objectives

The University of Michigan Air Quality Laboratory, in collaboration with the University of Vermont, and the Vermont Monitoring Cooperative, initiated atmospheric mercury and mercury cycling research at the Proctor Maple Research Center in Underhill, Vermont in 1992. Sponsored by EPA and NOAA, the station began an event-base sampling program for mercury in wet precipitation. Collecting rain and snowfall by storm event, rather than on a fixed sampling schedule, allows one to relate mercury concentration patterns in individual storms to air mass history by calculating back trajectories. The primary objectives of this project were to 1) complete analyses of event-based precipitation samples and bring historical records up to date, 2) continue year-round monitoring of atmospheric mercury in wet deposition and particulate phase in the Lake Champlain Basin (LCB), 3) investigate long-term trends in mercury deposition over the last decade in the LCB, and 4) determine major sources and atmospheric transport pathways for mercury into Vermont. The funds awarded to this research project were used exclusively to complete these program objectives.

Accomplishments/Results

- Mercury concentrations from individual precipitation events at Underhill ranged from ~0.9 – 90 ng/l over an 11-year period (1/1/93 – 12/31/03), with a volume-weighted mean event concentration of 8.9 ng/l. Factors such as season, type of precipitation, and meteorological transport history strongly influenced mercury concentrations at Underhill, while precipitation amount only explained about 20% of the variation.
- Event mercury wet deposition varied from ~0.002 – 1.8 ng/m^2 over this 11-year period, with an average event wet deposition of 0.10 ng/m^2. Clear monthly and seasonal t seasonal trends in total wet mercury deposition were found, with the highest values observed during spring and summer months and the lowest in winter months.
- Large deposition events (>0.4 ug/m^2) accounted for 20-60% of the monthly and 5-17% of the total annual mercury deposition at Underhill. Mercury levels at Underhill showed year to year variation without a clear upward or

downward trend. The highest mercury deposition events at Underhill traveled to Vermont along west-southwest and southerly transport corridors.

Publications

Keeler, Gerald J., Gratz, Lynne E. and Al-Wali, Khalid. (2005). Long-term atmospheric mercury wet deposition at Underhill, Vermont. *Ecotoxicology*, 14, 71-83.

Miller, E.K., VanArsdale, A., Keeler, G.J., Chalmers, A., Poissant, L., Kamman, N., and Brulotte, R. (2005) Estimation and mapping of wet and dry mercury deposition across Northeastern North America. *Ecotoxicology* 14, 53-70

Presentations

Keeler, Gerald J. (2004), Long-term atmospheric mercury wet deposition at Underhill, Vermont. Presentation given at the Annual Meeting of the Vermont Monitoring Cooperative, Burlington, VT, October 8, 2004.

Collaborations

Over the past decade atmospheric sampling has continued at Underhill making this Vermont dataset the longest continuous record of event-based mercury deposition in the United States, and possibly the world. These data have been integrated into ecosystem cycling studies looking at snow melt, stream export, and forest cycling including throughfall and leaf litter flux measurements. Because of the high quality and temporal resolution of these data, and location in the Lake Champlain basin, estimates of atmospheric mercury deposition measurement derived from the measurements at Underhill have been and are being used by more than a dozen scientists investigating mercury in terrestrial and aquatic ecosystems. These programs have fostered a community of researchers including atmospheric scientists, hydrologists, limnologists, ecologists, and biochemists actively collaborating to study the impacts of mercury on Vermont's and New England's ecosystems. These scientists represent several universities including the University of Vermont, Plattsburg State and St. Lawrence University, Dartmouth College, and University of Michigan, Vermont and New York Departments of Environmental Conservation, NOAA, US EPA, US Forest Service, the Vermont Monitoring Cooperative and at least one private environmental consulting company.

CA4/II-08: INVESTIGATION ON SOURCES AND SINKS FOR MERCURY IN LAKE CHAMPLAIN

Principal Investigators: Ning Gao, St. Lawrence University; Philip K. Hopke, Clarkson University; Richard Poirot, Vermont Agency of Natural Resources; and, Neil Kamman, Vermont Agency of Natural Resources

NOAA Strategic Goal 1

Overview and Objectives

The final date of this project was June 30, 2004. This summary provides a final report of this project, which was completed in fiscal year 2003-2004.

A detailed mercury balance model for Lake Champlain is essential for identifying the factors that control and moderate mercury accumulation in this freshwater body. The modeling efforts of this project are based on analysis of nearly a decade of quality data on atmospheric deposition of mercury (both wet and dry) from the Proctor Maple Atmospheric Station in Underhill, Vermont near the center of the basin, some historic data on streamflow Hg fluxes in basin streams, and a modest new data collection effort for Hg concentrations in the major inlet streams to Lake Champlain, its outlet, and the lake itself. The source-receptor modeling effort has revealed some significant correlations between Hg in Lake Champlain and certain types of emission sources and provided valuable source apportionment information on Hg. The mass balance model has provided evaluation on the importance of different input pathways to the lake, identified some data gaps that will soon be filled in by funded sampling work and hopefully by more future funding as well. A user interface has been created for the STELLA model so the modeling outputs could be displayed simultaneously and geographically for different lake segments. It could be used to model the effects of seasonal variation and annual fluctuation in various inputs and outputs. Currently the project is in full swing with source-receptor modeling in the verification phase, a mass balance model is still being refined and the important summer sampling in progress (see below).

There are several objectives associated with this project:

- Refine the mass balance model to include more detailed methylmercury speciation so its potential effect on bioaccumulation could be studied.
- Refine the mass balance model to include more accurate sedimentation process in the model. Not only will it help to gain a better understanding of mercury sedimentation and re-suspension processes in Lake Champlain, the sediment Hg flux record derived will also help to restore the historical patterns of regional and continental atmospheric emission and deposition.

- Enhance the STELLA mass model's graphic capabilities by exploring the possibility of a GIS linkage.
- Expand the regions for source-receptor modeling to uncover relevant emission sources, especially the ones located outside of the current studied region that are significant contributors of Hg to Lake Champlain via long-range transport.
- Refine the source-receptor modeling analysis to increase the accuracy for source apportionment.

Accomplishments

- Further refined a working mercury mass balance model for Lake Champlain that was constructed with the STELLA software program. This model has been improved over previous versions by incorporating physical pathways associated with mercury movement including atmospheric deposition, tributary input, revolatilization (out-gassing), dispersion, and advection. Some progress has also been made in linking the STELLA model to ArcView, a Geographic Information System software system that can expand the model's graphic capabilities.
- Sediment coring and analysis for total mercury and lead-dating have been completed at DEC-VT for three sites in the lake. Once equivalent data from lakebed areas of the different bays are attained, then a sedimentation component will be incorporated into the mass balance model.
- A manuscript has been submitted to Environmental Science and Technology based on the mass balance assessment of physical cycling of mercury in Lake Champlain.

Publications

Gao, N., N.G. Armatas, B., Puchalski, P.K. Hopke, and R. Poirot. 2004. A preliminary investigation into the possible emission sources for atmospheric mercury found in the Lake Champlain basin. In Lake Champlain: Partnerships and Research in the New Millenium, edited by T.O. Manley, P.L. Manley, and T.B. Mihuc. Kluwer Academic/Plenum Publishing, New York. pp.21-38.

Gao, N., N.G. Armatas, S. Drake, C. Cady, B. Olsen, J. Shanley, N. Kamman, G. Keeler, T. Scherbatskoy, T. Holsen, L. McIlroy. Submitted. A mass balance assessment for mercury in Lake Champlain. Environ. Sci. & Technol. Submitted July 1, 2004.

Presentations

Lafferty, K., and N. Gao. 2004. Identification of sources of fine particulate air pollutants in the Lake Champlain Basin using positive matrix factorization (PMF) analysis. Lake Champlain Consortium Student Conference, Middlebury College, April 24, 2004.

Krumhansl, K., and N. Gao. 2004. Identification of sources of mercury pollution in the Lake Champlain Basin using potential source contribution function (PSCF) analysis. Lake Champlain Research Consortium Student Conference, Middlebury College, April 24, 2004.

Significant Interactions

Due to the nature of this project, there have been multiple interactions about the principal investigators and co-principal investigators at St. Lawrence University, Clarkson University, and the DEC-VT. We have also maintained close contact with USGS-VT, LCRC, and NOAA/ARL. We also used opportunities to reach the general public through other organizations such as VMC (Vermont Monitoring Cooperative) and the Adirondack Research Consortium, St. Lawrence County Environmental Management Council.

Student Participation

Several undergraduate students participated in this project:

1. Nathan Gabriel Armatas, B.S. in Chemistry, SLU, May 2002. Currently a Ph.D. student in chemistry at Syracuse University.
2. Benjamin Puchalski, B.A. in Environmental Studies/Government, SLU. May 2003.
3. Mellisa Rury, B.S. in Chemistry, SLU, May 2003. Currently a Ph.D. student in chemistry at University of Maryland-College Park

CA4/II-09: LAKE ERIE HYDRODYNAMIC MODELING

Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The motivation for this project is to lay the groundwork for studying the relative roles of physical, chemical, and biological factors on the ecology of Lake Erie at a variety of space and time scales. Lake Erie was chosen as the target lake for several reasons including population density, availability of long term data sets, a variety of physical, chemical, and biological forcing functions (including invasive species), and a wide variety of impacts including water quality (hypoxia/anoxia), fisheries, and biological community structure. We believe that a reasonable initial approach would be to identify sources for and begin gathering data on the biological, chemical, and physical environment in Lake Erie. The data would be organized in a format that would be conducive to interdisciplinary analyses. The next step would be to develop a linked hydrodynamic/ecological model of Lake Erie including relevant physics (tributaries, advection, resuspension, etc.) and lower food web ecology. This project is intended to support the development of the Lake Erie hydrodynamic model which will eventually form the basis for the linked hydrodynamic/ecological model.

The specific objectives of this project are:

- Incorporation of ice, hydrology, storm climatology, and remote sensing data into the Lake Erie data base. The data base includes hourly surface meteorological data from U.S. and Canadian weather stations, Coast Guard Stations, buoys, and coastal marine stations around Lake Erie since 1950 as well as U.S. Army Corps of Engineers wave climatology information for 53 stations in Lake Erie. Meteorological parameters have been summarized on daily, monthly, and annual time scales.
- Development of a coupled hydrodynamic-ecological model of Lake Erie (in collaboration with J. DePinto, Limnotech Inc.). A 2 km hydrodynamic model grid will be established and the GLERL version of the Princeton Ocean Model will be implemented on this grid.

Accomplishments

- Continued development of the Lake Erie database. During this fiscal year, we collaborated with colleagues at CCIW/NWRI in Canada and as a result are adding current meter, thermistor, and transmissometer data from their extensive 2004 Lake Erie field program. We will are also adding ADCP and thermistor data from GLERL moorings in Lake Erie at Maumee Bay light, Maumee channel light, and the Cleveland Observation buoy as well as central and eastern basin over-winter moorings.

- Hydrodynamic model simulations in process: A 2 km hydrodynamic model grid was developed for use with the GLERL version of the Princeton Ocean Model. Daily tributary inflows and hourly meterology were assembled for the year 1994 and a complete hydrodynamic model simulation was accomplished. The high resolution (2 km) version of the Lake Erie hydrodynamic model is now operational and real-time results are available through the Lake Erie web site. The hydrodynamic model results were used with realistic phosphorus loadings from the tributaries to simulate spatially and temporally variable phosphorus concentrations in the lake. The results were calibrated with CCIW and EPA survey results for phosphorus concentrations. We are also continuing discussions with DePinto on how to interface hydrodynamic model output with his complete ecological model (implemented on the same computational grid).

Publications

None to date.

Presentations

Schwab, D.J., D. Beletsky, J. DePinto, and D. Dolan. 2005 Simulating phosphorus distribution in Lake Erie. Estuarine and Coastal Modeling, the 9th International Conference (submitted).

Beletsky, D., 2005. Climate and large lakes dynamics (Overview of CILER Task II). CILER Formal Review, June 1-2, Ann Arbor, MI.

Schwab, D.J., DePinto, J.V., Dolan, D.M., and Beletsky, D. 2005. High Resolution Model Study of Phosphorus Loading and Transport in Lake Erie. IAGLR-2005, 23-27 May, Ann Arbor, MI.

Schwab, D.J., D. Beletsky, and J. DePinto. 2004. Phosphorus loading and transport in Lake Erie. The 7-th International Marine Environmental Modeling Seminar, October 19-21, Washington, D.C.

Significant Interactions

We collaborated with Dr. L. Leon of the University of Waterloo on the hydrodynamic model simulations of thermal structure in Lake Erie.

CA4/II-11: MONITORING METEOROLOGICAL CONDITIONS ON LAKE CHAMPLAIN

Principal Investigators: Melody Burkins, The University of Vermont, Richard Furbush, The University of Vermont, and Carl Waite, The University of Vermont

NOAA Strategic Goal 3

Overview and Objectives

The need for real-time meteorological data from Lake Champlain to support lake research, enhance lake weather predictions, and aid in navigation was known for many years. The opportunity to establish such a meteorological monitoring station at Colchester Reef arose in 1996 with funding from NOAA, the Lake Champlain Research Consortium (LCRC), and the Lake Champlain Basin Program and availability of a suitable site at the Colchester Reef navigational light through the cooperation of the U.S. Coast Guard. In May 2004 a second on-lake meteorological monitoring station was established at Diamond Island (near Ferrisburg, VT), again, in cooperation with the U.S. Coast Guard, and with funding from the LCRC and NOAA.

Accomplishments

- Meteorological variables continue to be measured at both stations, including air temperature, relative humidity, wind speed and direction, barometric pressure, total solar irradiance, precipitation (non-freezing months) and water temperature measured at 87 feet msl. Data from both stations are saved as 15 minute averages (except for precipitation which is summed), automatically downloaded hourly (four 15 minute records), and immediately made available to the National Weather Service (NWS) and other users.
- All annual equipment calibrations for 2005 have been performed at the Colchester Reef station and will be completed at Diamond Island in the near future. These state-of-the-art automated monitoring stations provide high quality near real-time (1 hour delay) meteorological data to the NWS in

Burlington, a variety of researchers and resource managers, and to the general public, including, boaters and other recreational users of Lake Champlain. The NWS in turn makes these data available to the public over the internet at: http://www.erh.noaa.gov/er/btv/html/lake2.shtml and over the NOAA weather radio. The NWS uses these data to prepare wind and wave safety forecasts for commercial and recreational boaters and other lake users, and to anticipate and predict localized "lake effect" precipitation patterns. These valuable meteorological stations are operated and maintained by the Vermont Monitoring Cooperative (VMC) which is also responsible for data collection (data is downloaded to the VMC server) and management, much of the data distribution, and all data archiving. Additionally, management and maintenance of these stations are now considered core activities within VMC. It is imperative to keep all sensors calibrated and keep the station in top operating condition. This requires continued funding to provide the manpower, equipment/sensor updates, calibrations, and general site upkeep necessary to provide uninterrupted high quality data. The funds awarded to this research project have been used for these specific purposes.

Publications

The following Lake Champlain Research Consortium Monographs have used data from the Colchester Reef meteorological station:

Manley, T.O. Hydrodynamics of the South Main Lake and South Lake, Lake Champlain.

Manley, P.L., T.O. Manley, M.C. Watzin, and J. Gutierrez. Lakebed Pockmarks in Burlington Bay, Lake Champlain: I. Hydrodynamics and Implications of Origin.

Gao, N., N.G. Armatas, B. Puchalski, P.K. Hopke, and R.L. Poirot. A Preliminary Investigation into the Possible Emission Sources for Atmospheric Mercury Found in the Lake Champlain Basin.

Gao, N. A Mass Balance Assessment For Mercury In Lake Champlain. (in press)

Presentations

Near real-time data from Colchester Reef and Diamond Island are published on the internet, on an hourly basis, by the NWS (Burlington) at:
http://www.erh.noaa.gov/er/btv/html/lake2.shtml, on the Burlington Eco Info Project

(EMPACT) web site at: http://www.uvm.edu/%7Eempact/weather.php3, and on the VMC web site at: HTTP://SAL.SNR.UVM.EDU/VMC

Interactions

Broad support for these projects assuring the continuous stream of high quality meteorological data from Colchester Reef and Diamond Island has come from NOAA, LCRC, NWS, States of Vermont and New York, Middlebury College, the State University of New York at Plattsburgh, St. Lawrence University, St. Michael's College, and the University of Vermont, as well as, numerous businesses and the general public. One example of a significant collaboration is the Vermont Monitoring Cooperative's (VMC) relationship with the NWS. VMC, which is itself is a collaborative among the U.S. Forest Service, Green Mountain National Forest, State of Vermont, and University of Vermont, along with many cooperators, provides near real-time meteorological data from Colchester Reef and Diamond Island to the NWS for predictive purposes and distribution to the general public. VMC also functions as the archivist and data manager for the Colchester Reef and Diamond Island data, making the archived data available online and by request. The Colchester Reef and Diamond Island data are also used in collaborative projects between researchers at Middlebury College, Johnson State College, and the University of Vermont. Meteorological data from Colchester Reef and Diamond Island are among the most requested data provided to researchers, government agencies, and individuals by VMC. Recreational and commercial users of Lake Champlain, and lake researchers have come to depend on the near real-time meteorological data from these stations. Most recently, these data have been used to model the flow of mercury in the Lake Champlain Basin and vicinity

CA4/II-12: ESTABLISHMENT OF THE NATIONAL ATMOSPHERIC DEPOSITION PROGRAM

Overview and Objectives

The stated objective of the mercury deposition network (MDN) is to develop a national database of weekly concentrations of total mercury in precipitation and the seasonal and annual flux of total mercury in wet deposition. Data generated from the Vermont MDN station will also help support data needs for Vermont's long-term mercury monitoring program and adds baseline data to new, cutting-edge mercury research programs based at Underhill. Establishment of this site also adds a Vermont collection point to the developing national MDN database of measurements of total mercury in precipitation and helps cover current mercury deposition data gaps for the Northeast. This station enhances MDN's mercury

information with Underhill's established long-term record of an event-based mercury deposition monitoring program (including measurements of reactive phase mercury, particulates, trace-elements, air mass trajectories, and mercury speciation). The MDN data will be used to develop local, regional, and national information on spatial and seasonal trends in mercury deposited to surface waters, forested watersheds, and other sensitive receptors. All of the Underhill data taken together will yield a fairly complete picture of mercury concentrations and fluxes in northern Vermont and the Northeast. All of the funds provided toward this project were/will be used for station establishment, operation, and chemical analyses.

Accomplishments

- In July 2004 a new NADP/MDN monitoring station was installed at the established NADP VT99 site located at the Proctor Maple Research Center in Underhill Center, VT. The new MDN station officially began operation on July 27, 2004.

Publications

None to date.

Presentations

Miller, Eric (2005). Atmospheric Mercury in Rural Vermont. Presentation given at the Annual National Atmospheric Deposition Program Technical Meeting, Jackson, Wyoming, September 27 - 30, 2005.

Significant Interactions

The new MDN monitoring station at Underhill, VT is part of a multi-faceted approach to quantifying mercury levels and fluxes in the Lake Champlain Basin of Vermont. Mercury concentrations in precipitation and air have been continuously measured at Underhill since 1992, making this Vermont dataset the longest continuous record of event-based mercury deposition in the United States, and possibly the world. These data have been integrated into ecosystem cycling studies looking at snow melt, stream export, and forest cycling including throughfall and leaf litter flux measurements. Because of the high quality and temporal resolution of these data, and location in the Lake Champlain basin, estimates of atmospheric mercury deposition measurement derived from the measurements at Underhill have been and are being used by more than a dozen scientists investigating mercury in terrestrial and aquatic ecosystems. These programs have fostered a community of researchers including atmospheric scientists, hydrologists, limnologists, ecologists,

and biochemists actively collaborating to study the impacts of mercury on Vermont's and New England's ecosystems. These scientists represent several universities including the University of Vermont, Plattsburg State and St. Lawrence University, Dartmouth College, and the University of Michigan, Vermont and New York Departments of Environmental Conservation, NOAA, US EPA, US Forest Service, the Vermont Monitoring Cooperative and at least one private environmental consulting company. The Vermont MDN data greatly enhances the ever-increasing body of information being collected at Underhill, and the MDN network in return, benefits from the long-term Underhill mercury data.

COASTAL AND NEARSHORE PROCESSES

CILER research in coastal and nearshore processes has focused on both the marine and limnetic nearshore environments. CILER projects have studied coastal processes in the Great Lakes, Gulf of Mexico, South Atlantic Bight, and the northeastern coast of the United States. A particular emphasis has been the investigation of exchanges of materials from tributaries into the nearshore zone. Those investigations have covered a wide variety of disciplines including physical, chemical, and biological oceanography and limnology, and in many cases have combined all three fields. Several new research efforts have been launched to help model and forecast the transport of harmful algae and bacteria in the Great Lakes in order to advance capabilities for predicting beach closings and for monitoring overall water quality.

CA4/III-02: DEVELOPMENT AND CALIBRATION OF SEDIMENT TRANSPORT MODEL AND SPECTRAL WAVE-CURRENT BOUNDARY LAYER MODEL WITH IN SITU MEASUREMENT DATA

Principal Investigator: David Schwab, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The Episodic Events-Great Lakes Experiment (EEGLE) was undertaken to investigate the episodic sediment resuspension (or entrainment) events in the Southern area of Lake Michigan. The integrated hydrodynamic, wind-wave, and sediment transport model has been used to simulate the largest events of record in March 1998. The simulation results showed very similar patterns with the observed satellite image but missed some detailed features in magnitude and spatial distribution of resuspended sediment concentration. It is believed that the missing features may be attributed to several possible reasons including: (1) overestimation or underestimation of bottom shear stress induced by wave-current interaction; (2) spatial variation and error in critical shear stress and erosion rate estimation of bottom sediment; (3) different particle size distribution and flocculation effect; (4) non-uniform distribution of vertical sediment concentration profile; and (5) inaccuracies in the wave prediction model. To improve simulation results, a more accurate representation of bed shear stress induced by wave-current interaction in the hydrodynamic module and of sediment erodibility (critical shear stress and erosion rate) in the sediment module is of critical importance among these reasons.

The objectives of this research are focused on the development/implementation of new spectral wave-current boundary layer model and cohesive sediment resuspension model, and their calibration with in-situ measurement data. Thus, this research will be performed in two phases: (1) simultaneous measurements of flow field and sediment resuspension rate, and (2) development (or implementation of existing model) and calibration of spectral wave-current model and sediment resuspension model using in-situ measurement data. These objectives address key scientific areas under CILER's Task III research theme of coastal and nearshore processes.

Accomplishments

- A *in-situ* measurement system was deployed which consisted of: a new up-looking wave-measuring acoustic Doppler current profiler (ADCP) to measure directly two spectrums (energy spectrum and directional spectrum) of irregular waves and the current profile, and optical back-scattering sensors to measure sediment concentration. Two in-situ measurement systems were deployed at 10 m and 20 m water depths off of St. Joseph, MI in fall of 2002 as a part of EEGLE Project 5 by collaboration with Great Lakes Environment Research Laboratory (GLERL).
- The spectral wave-current boundary layer model and cohesive sediment resuspension model was developed and implemented.

Publications

Lee, C., Schwab, D.J. and Hawley, N. 2004. Sensitivity Analysis of Sediment Resuspension Parameters in Coastal Area of Southern Lake Michigan. J. Geophys. Res. (in press).

CA4/III-03: RAFOS AND SHELBURNE BAY PROGRAM

Principal Investigator: Thomas O. Manley, Middlebury College

NOAA Strategic Goal 1

Overview and Objectives

When considering that most effluent and intake pipes in Lake Champlain are located within the near shore region at depths less than 80 feet, is water quality affected by circulation dynamics or is it strictly a result of point or non-point source pollution entering these regions? Several years ago, two undergraduate theses suggested rather different results. When studying Town Farm Bay (at Thompsons

Point), Thompson (1994) found that Main Lake internal-seiche dynamics had a significant effect on the movement of water and some chemical constituents within this particular bay. Contrary to Thompson's observations, Sayward (1996) found that wind-driven circulation had a stronger effect on circulation within Burlington Bay than Main Lake internal seiche dynamics. Furthermore, Sayward showed the presence of a contour following circulation cell within Burlington Bay. This south to north flow showed a direct conflict between the outfall and intake pipes of the city of Burlington.

The Champlain Water District (CWD) is aggressively investigating the best methods by which cleaner water can be obtained from the lake. results from a pilot study in 1997 showed the presence of a strong diurnal internal-seiche that was not confined to Shelburne Bay itself. Rather, this internal seiche has a period some 4 times shorter than that of the Main Lake (Manley et al., 1999), and was possibly bounded to the north by Burlington Bay (Sardilli, 1999; Barsotti et al., 1999). Observations of internal surges (Hunkins et al., 1998) were also seen in the data obtained from this single mooring although not specifically mentioned by Sardilli. During periods of no stratification, flow dynamics in Shelburne Bay were uniform throughout the water column and much more sluggish than during stratified time periods. While not expected, the Acoustic Doppler Current Profiler (ADCP) recorded the presence of strong diurnal fluctuations in particle counts throughout the water column that were attributed to the movement of phytoplankton and/or zooplankton from early spring to late fall. Similarly, during the winter, vertical migrations of what appear to be Phantom Midges moved from the bottom to the near surface for foraging and then back to the bottom to avoid predation. Rose diagrams and hodographs suggested the presence of different circulation cells set up by wind forcing within the Bay itself. Unfortunately though, an average circulation within Shelburne Bay could not be definitively proven with this single mooring.

As a result of information gained from the Shelburne Bay pilot study, this one-year field program was staged within Shelburne and Burlington Bay's with an unprecedented amount of instrumentation from three institutions (NOAA/GLERL, Middlebury College and the CWD) in an effort to quantify the mean circulation of the region. There were a total of seven subsurface moorings, and nine perimeter sites deployed within this region. Perimeter sites were equipped with two temperature sensors; one close to the surface and the other near the bottom. Six of the seven subsurface moorings were located directly within Shelburne Bay; five equipped with ADCPs and thermistor strings while the most northern one was only equipped with a thermistor chain. The mooring located within the central region of Burlington Bay is part of a shared program between the Shelburne Bay project and a ground water

seepage study run by Patricia Manley and Mary Watzin. The Burlington Bay mooring is also equipped an ADCP, 2 thermistor chains, and an underwater photographic system. Additionally, four pressure-temperature recorders were temporarily placed along the perimeters of the two bays to look at lake level oscillations; in particular, surface seiches.

Shelburne Bay still remains an enigma with respect to its internal dynamics. While it does occasionally exhibit internal seiche oscillations at a period associated with that of the Main Lake (~ four days), it also exhibits a rather consistent diurnal (24 hour) period. Observations of both surface and deep currents have shown that the diurnal internal seiche period cannot be internal to Shelburne Bay. In order to account for bimodal circulation patterns set up within Shelburne Bay, the node (assuming uninodal structure) must be located to the north of Shelburne Bay and most likely in Burlington Bay. Two hypotheses have been proposed for the origin of the diurnal internal seiche within Shelburne Bay. First, it is created as part of a larger combined Burlington and Shelburne Bays system with the standing wave primarily aligned in a north-south direction. The second one requires a cross-lake internal mode existing from Willsboro Point to Shelburne Bay.

Accomplishments

- The results of the program provided a clear look into the short-term and long-term hydrodynamics of both Shelburne and Burlington Bays. For time spans less than several weeks, it was evident that both the diurnal and main lake seiches have an effect in Shelburne Bay however, both tend not to co-exist simultaneously. In 1997, there were no indications of the main lake seiche (4.5 days) in Shelburne Bay during the one-year study. Rather, a diurnal standing wave was the dominant system. In this more recent set of observations, the diurnal standing wave was dominant in the summer months while the main lake seiche was dominant during fall and spring. This was most likely due to specific stratification dynamics related to the Shelburne-Burlington Bay system. Surges emanating from the Main Lake and Burlington Bay impacted Shelburne Bay several times during stratified time periods. Their thermal structure was that of a rapidly moving bowl-shaped depression of the thermocline as it passed the sensors. It is believed that most if not all of the surge was dissipated within Shelburne Bay since no reflected pulse could be observed. Strong southerly wind events are believed to be the cause of these surges. The internal dynamics of Shelburne and Burlington Bay show very consistent back and forth motion above and below the thermocline.

- Statistically, the data show that the determination of the mean vector is not possible due to the low average and high standard deviations. The use of monthly hodograph diagrams of observed currents above and below the thermocline show a very consistent picture of counter clockwise circulation within Shelburne Bay. Long-term circulation patterns of Burlington Bay (Sayward,1996) would show a continuation of water flow to the north along the eastern side of Burlington Bay, there to finally exit out north of Colchester Reef. In summary, the original objectives were met and the mean circulation of the region was determined.

Publications

Gutierrez, Joshua, 2001. The General Pockmark in Burlington Bay, Lake Champlain, undergraduate thesis, Middlebury College, Dept. of Geology, 63 pp.

Manley, Patricia L., T. O. Manley, Mary C. Watzin and Josh Gutierrez, 2003. Lakebed Pockmarks In Burlington Bay, Lake Champlain: I. Hydrodynamics And Implications of Origin, in *Lake Champlain in Transition: Partnerships in Progress, Kluwer Academic, eds.,* Thomas O. Manley, Patricia L. Manley, and Timothy Mihuc.

Watzin, Mary. C., Patricia L. Manley, T. O. Manley, Sofia A. Kyriakeas, 2003. Lakebed Pockmarks In Burlington Bay, Lake Champlain II. Habitat Characteristics And Biological Patterns, in *Lake Champlain in Transition: Partnerships in Progress, Kluwer Academic, eds.,* Thomas O. Manley, Patricia L. Manley, and Timothy Mihuc.

Presentations

Manley, T. O., Circulation Dynamics of Shelburne Bay, Headquarters of the Champlain Water District, April, 29. 2000. (Invited talk)

Manley, T. O., Physical limnology of Lake Champlain (Invited 2 part lecture series), Fisheries Leadership Institute sponsored by Great Lakes Sea Grant, Valcour Conference Center; March 6, 2004.

Manley, T. O., The Hidden Wave Beneath the Lake, invited evening community lecture series sponsored by The Nature Conservancy, Skeensborough, NY, 17 Feb., 2004.

Manley, T. O., Sound and Lake Champlain Research, invited talk at the ECHO, Burlington, VT, Feb., 2005.

Manley, T. O., Water Motion of Lake Champlain, invited lecture at the Water Seminar Series of the Rubenstein School of Natural Resources, Univ. of Vermont, 29 March, 2005.

Manley, T. O., Water Quality and Hydrodynamics – A link, invited lecture at the American Water Resources Association Chapter at the Univ. of Vermont, 29 March, 2005.

Manley, T. O. and P. L. Manley, World and Local Research with Middlebury College Students, invited lecture at the South Street Presidential lecture series, Middlebury College, 6 May, 2005.

Significant Interactions

Work is continually ongoing in Shelburne Bay as a direct result of these program results. At this pointing time, the Champlain Water District is going to put in a second water intake in Shelburne Bay in a move to improve water quality prior to processing. The location of this second intake is critical to the success of their program. Efforts are now moving towards the determination of biomass species and suspended sediment in the water column at two specific locations in the bay.

Student Participation

Gutierrez, Joshua, B.A. degree, Middlebury College. 2001. Thesis: The General Pockmark in Burlington Bay, Lake Champlain, undergraduate thesis, Dept. of Geology, 63 pp.

CA4/III-06: NEARSHORE TRANSPORT: MODELING OBSERVATIONS AND BEACH CLOSURE FORECASTING

Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 3

Overview and Objectives

The Great Lakes respond very quickly to atmospheric forcing and other loadings. Consequently water quality managers and other planning and decision entities are increasingly calling for up-to-the-minute data on present water quality conditions or forecasts of these data that can be used to adjust or respond to quickly developing

activities with environmental implications. Examples include the forecast of short term water quality conditions for the withdrawal of water for drinking water supply; short range predictions of potentially dangerous conditions at water supply intakes; the forecast of beach closings and openings from bacterial contamination from combined sewer overflow (CSO) discharges.

For these and other reasons, the Great Lakes Forecasting System (GLFS, Bedford and Schwab, 1994; Schwab and Bedford, 1994) has been developed to provide short-range operational (regularly scheduled) predictions of such conditions for the open waters of the Great Lakes. Predictions include every-six-hour nowcasts and twice-a-day short-range (48 hr) forecasts. Variables predicted include the three-dimensional velocity field, the three-dimensional temperature field, the water level distribution and the wind wave height, length, period, and direction.

When contrasting the information needs of water quality managers with the forecasting experience to date, three issues remain. First, the information requirements all occur with regard to activities in, near, and around the near-shore/inshore zone. It is well known that greatest demand for lake/coastal resources is in the near-shore zone and accurate information is required in this zone. Second, the information needs of the managers are for water quality data; data not yet predicted or available in forecast form. Third, the water quality forecasts require knowledge of both point and non-point sources. This research program will focus on point source loadings of *E. coli* (EC) into coastal environments from particular rivers and its impact on beach closures.

Both numerical modeling efforts and integrated field activities are proposed to characterize the study region and test model adequacy. A modeling hierarchy based upon the GLFS can accurately forecast the need for beach advisories and for the first time credible real-time short-range forecasts will be possible. Additional benefits will also include the potential to forecast other water quality variables of interest and the general applicability of this modeling system to other sites in the Great Lakes.

The objectives of this project are:

- Develop a modeling system based upon a fully three-dimensional hydrodynamic model (GLFS) for forecasting E. coli and Enterococci concentrations along Great Lakes coasts impacted by a specific plume (ultimately pathogens).

- Test model adequacy with extensive comparisons to data obtained from moored current meters, dye studies, and in situ water quality sampling.
- Determine the extent of ecological consequences from model simulations under various weather and loading conditions and if a well-constrained set of ecological outcomes exists.

Accomplishments

- Began developing a nested grid hydrodynamic modeling system for the Great Lakes. Currently, the system is being tested with open boundary conditions derived for wind-driven circulation in the idealized circular paraboloid basin resembling southern basin of Lake Michigan.

Presentations

Beletsky, D., 2005. Climate and large lakes dynamics (Overview of CILER Task II). CILER Formal Review, June 1-2, Ann Arbor, MI.

Schwab, D.J. and D. Beletsky. 2005. Progress on CEGLHH hydrodynamics project and plans for 2005. All-PI meeting (2) for the Center of Excellence for Great Lakes and Human Health. April 19-20. East Lansing, MI.

Significant Interactions

We interacted with Dr. Walter Frick (EPA) and Dr. Richard Whitman (USGS) in the course of this project.

CA4/III-06: Forecasting Beach Closing: Harmful Algal Blooms and Water Quality in the Great Lakes

Principal Investigators: Stephen B. Brandt, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 3

Overview and Objectives

The FY 2005 Congressional Appropriations Bill containing NOAA's budget included language indicating that Congress "... expects NOAA to report to the Committee by July 31, 2005 on the development of forecasting models for beach closings in southern Lake Michigan, with specific attention to possible impacts of sewage overflows." In May 2004, NOAA's Great Lakes Environmental Research Laboratory

(GLERL) was designated as a Center of Excellence for Great Lakes and Human Health within NOAA. One of the initial projects of the Great Lakes Center involves developing high resolution hydrodynamic models for shoreline areas in the Great Lakes where there are beaches that could be susceptible to contamination from tributary discharges. These models would be used to forecast water quality at the beaches and could be used as guidance for beach managers in assessing water quality safety.

Accomplishments

- The NOAA Center of Excellence for Great Lakes and Human Health was established at GLERL. This center will conduct the scientific research necessary to develop forecasting models of water quality that can be used directly to reduce risks to human health.

- One of the initial research tasks of the Center of Excellence at GLERL is called "**Near-Shore Transport: Modeling, Observations, and Beach Closure Forecasting**." This task addresses the fact that the fate of contaminant loadings in the Great Lakes often depends critically on lake currents and that improved, high resolution models of lake currents need to be developed.

- Although the Near-Shore Transport project is still in its infancy, some of the technology to be used in this project has already been applied to a specific contamination incident due to sewage overflows in Milwaukee, Wisconsin in May 2004. Computer simulations of Lake Michigan circulation during May and June of 2004 show that water from the Milwaukee River could not be transported as far south as Chicago during this period.

In addition to these three areas in which progress has already been made, future directions in numerical modeling and field work necessary to develop more accurate and beach-specific forecasting tools are discussed.

CA4/III-07: Improved Understanding and Forecasting of Viral and Bacterial Sources and Transport in the Great Lakes

Principal Investigators: Joan B. Rose, Michigan State University

NOAA Strategic Goal 3

Overview and Objectives

The objectives associated with this project are as follows:

- Examine recreational beach waters at Huntington Beach, OH (Lake Erie) for the presence of enteric viruses and a human specific gene marker in *Enterococci*
- Develop a fecal pollution transport model for Lake Michigan
- Conduct a groundwater quality investigation at Put-in-Bay, Lake Erie, OH.
- Evaluate contribution of combined sewage overflow bacteria, *Cryptosporidium* and *Giardia*, to the waters of Lake Michigan.
- Assess the survival of *Cryptosporidium* and *Giardia* in Michigan waters.
- Investigate the role of sediments in serving as reservoirs for bacteria and pathogens.
- Assess microbial transport in laboratory aquifer columns.
- Develop a finite element model of nearshore circulation and transport.

Accomplishments

- Samples collected in 2003 were examined via cell culture and cell culture-PCR for the presence of human enteric viruses. In addition, 118 beach water samples were screened for the presence of the *esp* gene, a human specific gene marker within the *Enterococci* family.
- To help develop a model for the transport and fate of fecal pollution indicators in Lake Michigan, water samples were collected in summer 2004 at three Lake Michigan beaches and two tributaries draining into Lake Michigan. Samples are currently being analyzed for *E. coli* and *Enterococci* and for analysis for the *Enterococcus* human fecal pollution marker. These data will be used to develop a model for the near-shore transport and fate of fecal pollution in Lake Michigan.
- To study the occurrence of waterborne pathogens in groundwater, 16 utility wells on the island were sampled for traditional and alternative indicator organisms as well as pathogenic organisms including total coliforms, *Escherichia coli*, *Enterococci*, coliphage, *Clostridium perfringens*, *Salmonella*,

Campylobacter, protozoa (*Giardia* and *Cryptosporidium*) and enteric viruses. Eleven out of 16 wells (68.75%) were positive for total coliforms and at least one other organism tested. *Campylobacter upsaliensis* was found in one well while Campylobacter-like *Arcobacter butzleri* was isolated from six wells. Four of the wells that were positive for either *Campylobacter* or Camplybacter-like organism also tested positive for *Enterococci*, coliphage, and traditional indicators. No enteric virus was identified through cell culture; *Adenovirus* was detected in two wells through direct PCR detection. None of the wells were positive for *C. perfringens* or protozoa. The results of this study show that groundwater on South Bass Island on Lake Erie was heavily contaminated by human enteric organisms. Failure of septic systems was suspected to have contributed to the contamination.

- Laboratory experiments have been developed and implemented to help to understand factors that influence the transport of pathogens and fecal pollution indicator bacteria (*Escherichia coli, Enterococci* and *Cryptosporidium)* through soil columns. We designed PVC columns of different lengths and diameters (fitted with a number of stainless steel ports for detailed spatial sampling) to operate under a variety of conditions (e.g., different flow rates, sediment packings with different organic material content). We are conducting multiple tracer studies using fluorescein, bromide and tritium as conservative tracers to estimate dispersion as a function of flow rate in the column. We are planning to use bacterial and viral tracers, as well as particles that mimic the behavior of protozoan parasites (such as *Cryptosporidium* and *Giardia*). The spatial and temporal resolution in these experiments coupled with high-resolution numerical modeling will allow us to generate high-quality breakthrough curves that will be used to estimate parameters as well as to test our hypotheses. The experiments are being conducted using sediment material taken from Michigan aquifers (e.g., the Schoolcraft site in western Michigan). The insights that we gain from this effort will also help us in analyzing and interpreting groundwater quality data. The column models can be extended to a field setting in the future.
- Initial steps have been taken to develop a finite element model of wind-driven circulation and transport for Lake Michigan based on the RMA-10 and RMA-11 suite of models. We applied the models for a number of test cases to understand issues related to convergence, accuracy and stability. We will soon refine our finite-element model for Lake Michigan. Our immediate goal is to continue to refine this modeling, compare the circulation patterns with those produced by finite-difference models such as the Princeton model and develop a microbial transport model for the near-shore regions. By the end of

the year (2005), we plan to communicate at least one paper to a peer-reviewed journal based on these model inter-comparisons and comparisons with our observations in Michigan and Indiana beaches.

LARGE-LAKE ECOSYSTEM STRUCTURE AND FUNCTION

In the past few decades, environmental scientists have become increasingly aware of the complex physical, chemical, biological, and ecological relationships that contribute to ecosystem structure and function. Ecosystem studies of large lakes generally strive to examine not only the flora and fauna but also the physical and chemical environment and exchanges between land, water, and air. CILER research projects within this task are conducted by a cohort of physical, chemical, and biological scientists, similar to the projects in climate and large-lake dynamics and in coastal and nearshore processes. The primary distinction between large-lake ecosystem structure and function projects and other CILER projects is that the former are more focused on a specific aspect of large-lake structure and function.

CA4/IV-01: *CERCOPAGIS PENGOI*, A NEW INVADER OF LAKE MICHIGAN: FOOD WEB INTERACTIONS AND COMPETITION WITH *BYTHOTREPHES*

Co-Principal Investigators: Henry A. Vanderploeg, Great Lakes Environmental Research Laboratory and Radka Pichlová, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

There has been great concern that invading predatory cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* have been negatively affecting recruitment of larval perch and alewives in Lake Michigan. We proposed to develop a general model from experimental observations of prey selection and feeding for *Cercopagis* and *Bythotrephes* that will be useful for predicting predatory impact of these cercopagids. We will combine this information along with field observations of population dynamics, production and spatial distribution of zooplankton and fishes collected in this and related projects to describe and understand invasion dynamics of *Cercopagis* and determine if these cercopagids have disrupted the Lake Michigan food web. We hypothesize that alewife predation on *Bythotrephes*, a competitor and predator of *Cercopagis*, has allowed *Cercopagis* to invade nearshore waters of the spatially complex Lake Michigan. We are also examining whether both these cercopagids have created a bottleneck for recruitment of young of year alewife and other fishes.

Accomplishments

- We continued to examine prey selection by all instars of Bythotrephes and Cercopagis to determine their feeding rates and prey selection with focus of determining predation and prey selection at low concentrations of prey and carefully examining selection in multi-species prey assemblages. We explored the possibility that two of three species of Daphnia that disappeared from the Great Lakes when Bythotrephes invaded did so because they had weak escape response from Bythotrephes attacks. This was done by examining Bythotrephes predation for these species offered together in bottles and prey escape response observed directly in the cinematography lab. All samples from experiments were processed and data summarized and partly analyzed. The analysis of videotapes on prey escape response at Bythotrephes presence is close to completion.
- We made much progress on determining population dynamics of *Bythotrephes*, *Cercopagis*, *Leptodora* (a spineless native predatory cladoceran) and their zooplankton prey from net tow collections made in 2000-2003—All zooplankton from Stations M15, M45, and M110 have been counted and their biomass determined for 153 μm net collections. We determined that *Bythotrephes* predation on *Cercopagis* probably controls spatial distribution of *Cercopagis*. We need now to compare prey consumption of the cercopagids with that of alewives and determine impacts to the zooplankton community and alewives.
- We reexamined alewife diet and selectivity data to compare selection of alewives for both *Bythotrephes* and *Cercopagis*, and we presented evidence that fish predation regulated establishment of *Bythotrephes* and *Cercopagis* in the Great Lakes. We did intense diel sampling (every four hours) in August 2004 of: zooplankton distribution by net tows, pumping, and plankton survey system (PSS); fish distribution by acoustics; and fish in trawls for diet analyses at a deep (60 m) and shallow (10 m) stations near Muskegon, Michigan, during the time period of the full moon and the new moon to determine spatial and predatory interactions among *Bythotrephes*, *Cercopagis*, alewives, and zooplankton under different light conditions.
- We determined that the strong preference of fish (alewives) for *Bythotrephes* over *Cercopagis* might allow *Cercopagis* to exist in Great Lakes where fish control *Bythotrephes* abundance. We are working with USGS Great Lakes Science Center personnel to examine this hypothesis in greater detail. A corollary hypothesis is that fish predation pushes the size of zooplankton downward favoring the smaller predator, *Cercopagis*.

- On both full moon and new moon cruises we obtained both cross-isobath (M10-M110) simultaneous acoustic and PSS transects during day and night that will allow us to examine spatial distribution of fish and total zooplankton biomass. At M10 and M60 we did simultaneous PSS and acoustics runs on ~ 4 h intervals and did opening/closing net sampling in epi-, meta-, and hypolimnion, and pumping for zooplankton at multiple depths (6 depths at M60 and 2 at M10) to get fine scale vertical distribution of different zooplankton species.
- On both cruises we managed to collect fish (alewives primarily) at most 4-h sampling intervals at M10—This will allow us to determine diel periodicity of feeding and prey selection, as well estimating ration of the fish at this station after examining diet, stomach content weight, fish weight, and abundance of zooplankton from net tows. (Low abundance of alewives and gear problems prevented collection in bottom and midwater trawls at the offshore station.
- Preliminary analyses of the data showed that thermal structure strongly regulated zooplankton distribution. The analysis of data has meanwhile considerably progressed and should be finished soon.

Publications

Henry A. Vanderploeg, Stephen A. Pothoven, Robert O'Gorman, Charles P. Madenjian, Jeffrey S. Schaeffer, David M. Warner, Radka Pichlová, and James R. Liebig: Large planktivorous fish mediated invasion dynamics, establishment, and coexistence of two predatory cladocerans in the Great Lakes. (Currently working on resubmission).

Radka Pichlová, and Henry A. Vanderploeg: Does predation of *Bythotrephes longimanus* regulates spatial distribution of another invasive predatory cladoceran, *Cercopagis pengoi*? (Currently working on resubmission)

Pothoven, S.A., and Vanderploeg, H.A.: Prey selection and diet of alewife in Lake Michigan: seasonal, spatial, and interannual patterns. 2004. Trans. Amer. Fish. Soc. 133: 1068-1077.

Presentations

"Second International Cercopagid Workshop", April 26-28, 2005, Queen's University Biological Station (QUBS), Ontario, Canada. Pichlová, R.: Selectivity for prey by Bythotrephes (Oral).

"International Association of Great Lakes Research" - annual meeting, May 23-27, 2005, Ann Arbor, Michigan, USA. Pichlová, R., Vanderploeg, H. A., Cavaletto J. F.: Comparison of *Bythotrephes longimanus* and *Cercopagis pengoi* impacts on Lake Michigan food webs (Oral).

"ASLO 2005 Summer meeting", June 19 – 24, 2005, Santiago de Compostela, Spain. Pichlová, R., Vanderploeg, H. A., Cavaletto J. F.: Effecs of two invasive invertebrate predators, *Bythotrephes longimanus* and *Cercopagis pengoi* on zooplankton community in Lake Michigan (Oral).

Vanderploeg, H. A., Pothoven, S. A., O'Gorman, R. O., Madenjian, C. P., Schaeffer, J. S., Warner, D. M., Pichlová, R, Liebig, J. R.: Fish predation mediated the invasion dynamics and establishment of two predatory cladocerans in the Great Lakes (Oral)

CA4/IV-05: IMPLICATIONS OF CERCOPAGIS AND BYTHOTREPHES TO ALEWIFE RECRUITMENT AND STABILITY OF THE LAKE MICHIGAN PELAGIC FOOD WEB

Principal Investigators: Henry Vanderploeg, Great Lakes Environmental Research Laboratory; Doran Mason, Great Lakes Environmental Research Laboratory and Radka Pichlová, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

There has been great concern that invading predatory cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* have been negatively affecting recruitment of larval perch and alewives in Lake Michigan. We proposed to develop a general model from experimental observations of prey selection and feeding for *Cercopagis* and *Bythotrephes* that will be useful for predicting predatory impact of these cercopagids. We will combine this information along with field observations of population dynamics, production and spatial distribution of zooplankton and fishes collected in this and related projects to describe and understand invasion dynamics of *Cercopagis* and determine if these cercopagids have disrupted the Lake Michigan food web. We hypothesize that alewife predation on *Bythotrephes*, a competitor and predator of *Cercopagis*, has allowed *Cercopagis* to invade nearshore waters of the spatially complex Lake Michigan. We are also examining whether both these cercopagids have created a bottleneck for recruitment of young of year alewife and other fishes.

Project Objectives

- Determine prey selection and consumption by Cercopagis and Bythotrephes for major crustacean zooplankton taxa, rotifers, and Dreissena in Lake Michigan and other Great Lakes using traditional bottle or enclosure experiments and video observations of predation mechanisms.
- Examine impact of Cercopagis and Bythotrephes on nearshore prey field in Lake Michigan utilized by larval and YOY fishes and evaluate consequences to fishes.
- Evaluate the role of adult alewives in regulating spatial distribution and predatory and competitive interactions between Cercopagis and Bythotrephes and this regulation's impact to larval fishes.

Accomplishments

- We continued to examine prey selection by all instars of *Bythotrephes* and *Cercopagis* to determine their feeding rates and prey selection with focus of determining predation and prey selection at low concentrations of prey and carefully examining selection in multi-species prey assemblages. We explored the possibility that two of three species of *Daphnia* that disappeared from the Great Lakes when *Bythotrephes* invaded did so because they had weak escape response from *Bythotrephes* attacks. This was done by examining *Bythotrephes* predation for these species offered together in bottles and prey escape response observed directly in the cinematography lab.
- All samples from experiments have been processed and the data summarized and partly analyzed. The analysis of videotapes on prey escape response at *Bythotrephes* presence is close to completion.
- We made much progress on determining population dynamics of *Bythotrephe*s, *Cercopagis*, *Leptodora* (a spineless native predatory cladoceran) and their zooplankton prey from net tow collections made in 2000-2003—All zooplankton from Stations M15, M45, and M110 have been counted and their biomass determined for 153 μm net collections. We determined that *Bythotrephes* predation on *Cercopagis* probably controls spatial distribution of *Cercopagis*. We need now to compare prey consumption of the cercopagids with that of alewives and determine impacts to the zooplankton community and alewives.
- We reexamined alewife diet and selectivity data to compare selection of alewives for both Bythotrephes and Cercopagis, and we presented evidence

that fish predation regulated establishment of Bythotrephes and Cercopagis in the Great Lakes. We did intense diel sampling (every four hours) in August 2004 of: zooplankton distribution by net tows, pumping, and plankton survey system (PSS); fish distribution by acoustics; and fish in trawls for diet analyses at a deep (60 m) and shallow (10 m) stations near Muskegon, Michigan, during the time period of the full moon and the new moon to determine spatial and predatory interactions among Bythotrephes, Cercopagis, alewives, and zooplankton under different light conditions. We determined that the strong preference of fish (alewives) for Bythotrephes over Cercopagis might allow Cercopagis to exist in Great Lakes where fish control Bythotrephes abundance. We are working with USGS Great Lakes Science Center personnel to examine this hypothesis in greater detail. A corollary hypothesis is that fish predation pushes the size of zooplankton downward favoring the smaller predator, Cercopagis.

- On both full moon and new moon cruises we obtained both cross-isobath (M10-M110) simultaneous acoustic and PSS transects during day and night that will allow us to examine spatial distribution of fish and total zooplankton biomass. At M10 and M60 we did simultaneous PSS and acoustics runs on ~ 4 h intervals and did opening/closing net sampling in epi-, meta-, and hypolimnion, and pumping for zooplankton at multiple depths (6 depths at M60 and 2 at M10) to get fine scale vertical distribution of different zooplankton species.
- On both cruises we managed to collect fish (alewives primarily) at most 4-h sampling intervals at M10—This will allow us to determine diel periodicity of feeding and prey selection, as well estimating ration of the fish at this station after examining diet, stomach content weight, fish weight, and abundance of zooplankton from net tows. (Low abundance of alewives and gear problems prevented collection in bottom and midwater trawls at the offshore station.
- Preliminary analyses of the data showed that thermal structure strongly regulated zooplankton distribution. The analysis of data has meanwhile considerably progressed and should be finished soon.

Publications

Henry A. Vanderploeg, Stephen A. Pothoven, Robert O'Gorman, Charles P. Madenjian, Jeffrey S. Schaeffer, David M. Warner, Radka Pichlová, and James R. Liebig: Large planktivorous fish mediated invasion dynamics, establishment,

and coexistence of two predatory cladocerans in the Great Lakes. (Currently working on resubmition)

Radka Pichlová, and Henry A. Vanderploeg: Does predation of Bythotrephes longimanus regulates spatial distribution of another invasive predatory cladoceran, Cercopagis pengoi? (Currently working on resubmission)

Pothoven, S.A., and Vanderploeg, H.A.: Prey selection and diet of alewife in Lake Michigan: seasonal, spatial, and interannual patterns. 2004. Trans. Amer. Fish. Soc. 133: 1068-1077.

Presentations

"Second International Cercopagid Workshop", April 26-28, 2005, Queen's University Biological Station (QUBS), Ontario, Canada Pichlová, R.: Selectivity for prey by Bythotrephes (Oral).

"International Association of Great Lakes Research" - annual meeting, May 23-27, 2005, Ann Arbor, Michigan, USA. Pichlová, R., Vanderploeg, H. A., Cavaletto J. F.: Comparison of *Bythotrephes longimanus* and *Cercopagis pengoi* impacts on Lake Michigan food webs (Oral).

"ASLO 2005 Summer meeting", June 19 – 24, 2005, Santiago de Compostela, Spain. Pichlová, R., Vanderploeg, H. A., Cavaletto J. F.: Effecs of two invasive invertebrate predators, *Bythotrephes longimanus* and *Cercopagis pengoi* on zooplankton community in Lake Michigan (Oral).

Vanderploeg, H. A., Pothoven, S. A., O'Gorman, R. O., Madenjian, C. P., Schaeffer, J. S., Warner, D. M., Pichlová, R, Liebig, J. R.: Fish predation mediated the invasion dynamics and establishment of two predatory cladocerans in the Great Lakes (Oral).

Interactions/Collaborations

Bob O'Gorman, Chuck Madenjian, Jeff Schaeffer of USGS Great Lakes Science Center are providing alewife biomass estimates on Lakes Michigan, Huron, and Ontario, and helping with writing a manuscript on fish predation regulating invasions of *Bythotrephes* and *Cercopagis* in the Great Lakes.

Student Participation

There was not any student working on a degree on this project, however, we have employed and mentored altogether three summer-intern students who helped considerably with experimental work and samples processing.

- Quy Thai (graduate student), 3 months, July-September 2004
- Feng Li (high school student), 2 months, July-August 2004
- Deanna Frankowski (graduate student), 3 months, June-August 2005

CA4/IV-06: Status and Trends of Benthic Macroinvertebrates in Lake Michigan

Principal Investigator: Tom Nalepa, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The objective of this program is to document long term trends of benthic macroinvertebrate populations in Lake Michigan. By documenting changes in abundances of the major benthic groups (*Diporeia*, Oligocheata, Chironomidae, Shaeriidae, and *Dreissena*) we can get an indication of shifts the general ecological health of the lake. This program was initiated in 1980 and samples have been collected at 40 sites in the southern portion of the lake in 1980-81, 1986-87, 1992-93, and 1998-99. In addition, samples were taken throughout the entire lake in 1994/95 and 2000. Over this period of several decades, some dramatic changes have occurred as related first to nutrient enrichment and then abatement, and then to invasive species. Of special interest are density trends in *Diporeia*, a cold-water amphipod important in the diet of fish, and the invasive mussels *Dreissena polymorpha* (zebra mussel), and *Dreissena bugensis* (quagga mussel). *Diporeia* populations, first started to decline in the southeast portion of the lake in 1992, but declines are now apparent throughout. Between 1994/95 and 2000, lakewide declines were 78%, 74%, 53% and 52% at sites in the < 30 m, 31-50 m, 51-90 m, and > 90 m depth intervals, respectively. *Diporeia* are now totally absent from large portions of the lake. Over this same time period, the zebra mussel population expanded, with greatest density increases occurring at 31-50 m. Furthermore, densities of quagga mussels also increased. This species is now more abundant than zebra mussels at most locations. The expected expansion of the quagga mussel population will lead to further declines in *Diporeia*, which will likely then lead to greater impacts on fish species that feed on this amphipod.

Accomplishments

- For the monitoring program in the southern basin, samples were collected at the same 40 sites in spring, summer, and fall 2004, and spring and summer 2005. This keeps with the original sampling design of sampling for two consecutive years every 5 years.
- Samples were also collected at 160 sites throughout the lake in July 2005. All these sites were sampled previously in 2000. Benthic organisms in these samples continue to be counted and sorted by major group.

Publications

Nalepa, T. F., Fanslow, D. L., Lang, G. A., and Ruberg, S. A. 2005. Recent trends in benthic macroinvertebrate populations in Lake Michigan. *In* State of Lake Michigan: Ecology, Health, and Management. Edited by T. Edsall and M. Munawar. Ecovision World Monograph Series. Goodword Books Ltd., New Delhi, India

Nalepa, T. F., Fanslow, D. L., and Foley, A. J. III. 2005. Spatial patterns in population trends of the amphipod *Diporeia* spp. and *Dreissena* mussels in Lake Michigan. Verh. Internat. Verein. Limnol. 29: 426-431.

Nalepa, T. F., Fanslow, D. L., Foley, A. J., Lang, G. A., Eadie, B. J., and Quigley, M. A. Continued disappearance of the benthic amphipod *Diporeia spp*. in Lake Michigan: is there evidence for food limitation? Can. J. Fish. Aquat. Sci. (submitted).

Presentations

Nalepa, T. F. 2005. Aquatic invasive species and food web disruptions in the Great Lakes. Invaders of the Great Lakes: Options for Prevention and Management. Conference, Michigan State University, East Lansing, MI. March, 2005.

Nalepa, T. F. 2005. Food web disruptions in the context of invasive species and other stressors. Aquatic Invasive Species Symposium, National Wildlife Foundation, Chicago, IL. May, 2005.

Nalepa, T. F., Fanslow, D. L., and Foley, A. J. 2005. Declines in the benthic amphipod Diporeia spp. in the Great Lakes: is there evidence for food limitation? ASLO 2005 Summer Meeting, American Society of Limnology and Oceanography, Santiago, Spain. June, 2005.

Significant Interactions

This project interacted with Great Lakes National Program Office, EPA, which provided use of the R/V Lake Guardian.

CA4/IV-09: Ecology of Lake Whitefish Responses to Changes in Benthic Communities in Lake Huron

Principal Investigator: Thomas Nalepa, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The lake whitefish *Coregonus clupeaformis* is the most important commercial fish species in Lake Huron. The harvest of lake whitefish is approximately 4 million pounds per year, more than the total sport and commercial harvest of all other species combined. Tribal and state commercial fishermen have recently reported decreases in condition of lake whitefish in Lake Huron, expressing concern about the stability of this important fishery. The decline in condition of lake whitefish has economic implications as harvest and marketability of lake whitefish decrease. Lake whitefish in poor condition could also experience poor reproductive success and recruitment, leading to a decline in the fishery. Additionally, some reports indicate that lake whitefish may be moving to deeper water where food such as *Diporeia* are more abundant. If lake whitefish are moving to deeper water, they may not be legally or practically accessible to commercial fisheries. Also, changes in the thermal regime experienced by lake whitefish in deeper water could also affect growth.

In Lake Michigan, similar declines in condition of lake whitefish were attributed to a combination of factors, including consumption of low-quality food items such as zebra mussels and sphaeriids, and declines of the high-energy food item *Diporeia* (Pothoven et al. 2001). Following declines of *Diporeia* off Muskegon, MI between 1998 and 1999-2000, the contribution of *Diporeia* in the diet of lake whitefish fell from 61% to 18% by weight (Pothoven et al. 2001). Understanding diet patterns and bioenergetics of lake whitefish was recently identified as a top-priority research item for funding by the Lake Huron Technical Committee, under the auspices of the Great Lakes Fishery Commission. There is very little diet data available for lake whitefish in Lake Huron or in the other Great Lakes.

The objectives of this study were:

- To quantify lake whitefish diet and feeding patterns in two regions of western Lake Huron.
- To evaluate current lake whitefish diet patterns relative to ongoing changes in the benthic prey community.
- To determine condition of lake whitefish in these two regions.

Accomplishments

- We quantified lake whitefish diet on a seasonal basis in two western Lake Huron management zones (WFH-06 and WFH-07). Diet was evaluated for different size classes of lake whitefish in each region for the 2002-04 and was compared to data collected from other areas of Lake Huron during this time period. Currently, the diet of lake whitefish in these areas is mainly zooplankton for age-0 fish, a combination of zooplankton, *Bythotrephes*, ostracods, midges and *Mysis relicta* for small fish, and quagga mussels *Dreissena bugenis* for large fish. The prey type eaten appeared to influence the amount of food eaten for age-0 and small lake whitefish and the energy consumed by small fish, but food types did not influence amount or energy consumed for larger fish. Small lake whitefish appear unable to utilize the invasive quagga mussels for food effectively. The dominance of quagga mussels in the diet of larger lake whitefish is likely a reflection of dramatic increased abundance of this prey since 2000. *Diporeia* abundance has declined dramatically in Lake Huron since 2000 and this trend was reflected in the low occurrence of this prey in lake whitefish diets. Condition was evaluated using data provided by the Michigan Department of Natural Resources and by determining whole body energy density. Condition has declined over time and is lower in Lake Huron than in Lake Michigan for similar sized fish. Several presentations were given to constituent and scientific audiences, a manuscript was submitted on energy density trends was submitted to *Environmental Biology of Fishes*, and a comprehensive manuscript on lake whitefish diet in Lake Huron is in progress.

Publications

Pothoven, S. A. 2005. Changes in lake whitefish diet in Lake Michigan, 1998-2001. pp. 127 – 140. *In* L. C. Mohr & T. F. Nalepa (eds.) Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod

Diporeia spp. in the Great Lakes. Great Lakes Fisheries Commission Technical Report 66, Ann Arbor, Michigan.

Pothoven. S. A. T. F. Nalepa, C. P. Madenjian, R. R. Rediske, P. J. Schneeberger, and J. X. He. Energy density of lake whitefish *Coregonus clupeaformis* in Lakes Huron and Michigan. Submitted to Environmental Biology of Fishes

Presentations

Pothoven, S. Lake whitefish diet and condition: Lakes Huron and Michigan. Jan. 15, 2005. Michigan Fish Producers Association, Traverse City, MI. Sponsored by Michigan Sea Grant.

Pothoven, S. A. and T. F. Nalepa. Feeding ecology of lake whitefish in Lake Huron. 48th Conference on Great Lakes Research, IAGLR, May 23-27, 2005; Ann Arbor, MI.

Pothoven, S. Lake whitefish diet and condition in Lakes Huron and Michigan. Lake Whitefish Natural Mortality Workshop-Great Lakes Fishery Commission. September 20-21, 2005. Ann Arbor, MI

Significant Interactions

This project has led to significant collaboration with the Michigan Department of Natural Resources (Alpena Field Station), United States Fish and Wildlife Department (Alpena), and Ontario Ministry of Natural Resources (Owen Sound). These agencies have provided data, lake whitefish biological samples, and benthic samples to supplement our field support for our research. In turn, data from this project has been shared with researchers at these agencies. The Thunder Bay Marine Sanctuary (NOAA) provided support for field operations.

CA4/IV-10: INVENTORIES OF PCBS IN THE DEPOSITIONAL SEDIMENTS OF LAKE MICHIGAN

Principal Investigators: Brian J. Eadie, Great Lakes Environmental Research Laboratory, John A. Robbins, Great Lakes Environmental Research Laboratory, Peter F. Landrum, Great Lakes Environmental Research Laboratory, and Thomas H. Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

In aquatic systems, rapid and efficient sorption and settling remove contaminants from the water column into the sediments. Large episodic events resuspend and transport materials from temporary sedimentary sinks to more permanent sinks with a small fraction becoming incorporated annually into the sediments of the depositional basins. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades presently results in much greater fluxes to the water column than from all external inputs. The focus of this effort is to measure inventories of PCBs in Lake Michigan sediments and use these data in lake-scale mass balance models.

During the extensive sediment collection cruises of 1994-95, GLERL selected 17 box cores for careful sectioning (1 cm or less intervals) for the purpose of analysis of trace organic contaminants, including PCBs. All cores were from the same box cores used for geochronology. Subsequent radionuclide analysis showed that most sites were worthy of further examination. Eight of these cores were extracted prior to the PI (Pat Van Hoof) leaving GLERL. All of the GC runs now exist as computer files.

The objective of this project is to convert the computer files into usable data, by passing them through the LMMB QA/QC. This method requires more than one day per slice. The original goal was to analyze nine of the datafiles from the cores; however, because of limited EPA funding, only two of the files from the cores could be analyzed. The two cores with highest temporal resolution have been selected (15, and 61) for final analysis for PCBs.

Accomplishments

- Two of the cores initially identified for data conversion were analyzed and the data were forwarded to appropriate contacts at the U.S. EPA.

Presentations

Eadie, B.J. Chemical Integrity of the Great Lakes – Current Research and Research Needs. State of the Lakes Environmental Conference, Binational Committee Meeting, Toronto, Ont, Ca. Oct 2004

Significant Interactions

The analyses were done under an IAG with EPA-GLNPO. They and EPA-Grosse Ile will be the main users of the data generated by Sander.

CA4/IV-11: Fish Recruitment Disruption Due to Invasive Predator Cladocerans: Density and Behaviorally Mediated Effects

Principal Investigator: Scott Peacor, Michigan State University

NOAA Strategic Goal 1

Overview and Objectives

The objectives of this project were to: 1) establish a protocol and setup to test behavioral response of Great Lakes zooplankton to their predators, in particular the invasive species, *Bythotrephes* and 2) to implement the protocol. This was accomplished by placing zooplankton in acrylic cylinders and using a pump system that flows resources and predator kairomones (i.e., scent) through the cylinders. Zooplankton were then observed to assess how different factors affect their behavior and growth rate.

Accomplishments

- Based on experimental results, we have determined that Great Lakes zooplankton respond strongly to predators and, importantly, to the invasive predatory cladoceran *Bythotrephes*. In particular, we have found that several species of cladocerans and two copepod species change their behavior in response to *Mysis*, *Bythotrephes*, and fish predators. In addition, we found that *Daphnia mendotae* responds in a predictable, yet qualitatively different, manner to *Bythotrephes* than is does to another invertebrate predator, *Mysis*.
- The type of behavioral response of the zooplankton appears to also have an impact on growth rate. This suggests that "trait-mediated interactions" of the predator on prey may contribute strongly to the net effect of the predator on prey.

Publications

Submitted:

Peacor, S.D., K. Pangle, and H. Vanderploeg. Behavioral response of Lake Michigan *Daphnia mendotae* to *Mysis relicta*. In review. Submitted to J. Great Lakes Res.

Close to submission:

Pangle, K.L., S.D. Peacor, et al. Anti-predator behavior elicited by a nonnative invertebrate predator: Lake Michigan *Daphnia* and *Bythotrephes*.

Presentations

IAGLR 2005, Ann Arbor, MI. Pangle, K.L., Peacor, S.D., Vanderploeg, H.A. Anti-predator behavior elicited by a nonnative invertebrate predator: Lake Michigan *Daphnia* and *Bythotrephes*.

Impact of Invasive Cercopagids Workshop, The Queen's University Biological Station, Kingston, Ontario. Pangle, K.L., Peacor, S.D. Anti-predator behavior elicited by a nonnative invertebrate predator: Lake Michigan *Daphnia* and *Bythotrephes*.

Significant Interactions

We have had extensive interaction with Ora Johannson of the Great Lakes Fishery Research Branch Canada Centre for Inland Waters (867 Lakeshore Road, P.O. Box 5050 Burlington, ON CANADA L7R 4A6). She has sent zooplankton samples collected in Lake Erie in the 1990s. Our analysis is helping her interpret how behavioral changes in zooplankton could be causing observed patterns.

Additional Funding

Fish recruitment disruption due to invasive predator cladocerans: density and behaviorally mediated effects, Great Lakes Fishery Commission, $173,657 (2004-07).

Student Participation

This project is funding Kevin Pangle, a Ph.D. student in the Fisheries and Wildlife Department at Michigan State University. Kevin will likely graduate in 3-4 years.

CA4/IV-12: Utility of Contaminant Body Residue as the Dose Metric for Contaminant Mixtures and Pulsed Exposures in Aquatic Toxicology

Principal Investigator: Peter F. Landrum, Great Lakes Environmental Research Laboratory, and Thomas H. Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

Standard regulatory paradigms such as water quality criteria use the environmental concentration as a surrogate for the concentration at the target site. These paradigms are based on the premise that the toxicant concentration at target site is proportional to the organism concentration, which is in turn proportional to the exposure concentration. Some limitations to this approach include difficulties in determining the bioavailable fraction of the environmental concentration, multiple uptake routes, and non-steady-state exposure situations (e.g., short exposure times). If effects were based on the body residue required to produce the effect, complications arising from the uncertainty regarding bioavailability and accumulation would essentially be eliminated. Further, for non-polar narcotic compounds, the toxicity appears to be additive so that mixtures can be addressed either through molar additivity or through a toxic unit approach. Therefore, expressing dose on a body residue basis, a reasonably new concept, has the potential to greatly improve our ability to assess risk. Most of the exposures that have been used to establish the use of body residues have been done with continuous or near continuous exposure and have not considered the impact of biotransformation. The application of the body residue approach to establish the dose metric needs to be confirmed with biotransformation addressed and with pulsed exposures. In these cases, the toxicokinetics and toxicodynamics will be critical features controlling organism response.

The proposed objectives for this project are to investigate the utility of the body residue approach to predict the toxic effects in organisms exposed intermittently to 1) one contaminant, 2) two contaminants with different elimination rate constants and the same mode of toxic action, and 3) two contaminants with different elimination rate constants and different modes of toxic action. These data will allow us to further address the following question: How can we interpret the significance of chemical residues in field-collected organisms intermittently exposed to various contaminants through multiple routes of exposure?

Accomplishments

- A Multi-component Damage Assessment Model (MDAM) with and without toxicokinetic interactions was developed to analyze the toxicity of PAH as a

mixture of the parent compound and metabolites. It was assumed that the cumulative damage is the determinant of the toxic response for the mixture toxicity. The effect of biotransformation on the toxicity of pyrene and fluorene in *Hyalella azteca* was investigates by co-exposure to pipernoyl butoxide (PBO), a biotransformation inhibitor. From MDAM, a time-dependent toxic unit (TU) analysis method was derived and applied for the parent compound ($TU_P(t)$), and metabolites ($TU_m(t)$) and the inhibitor ($TU_i(t)$). The TU_i was determined from exposures to DDE a compound that is not biotransformed by exposing the organisms with and without PBO. This allowed the determination of the toxicodynamic parameters for parent PAH and metabolites. The metabolites for pyrene were found to be non-toxic while those for fluorene were found to be more toxic than the parent compound. An experimental design was put forward to allow estimations of the toxicodynamic parameters for other compounds using the MDAM model. The studies to determine the impact of biotransformation were put in manuscript form and submitted.

- The second set of studies that were part of this work employed exposures of *Hyalella azteca* to pulsed exposures of selected contaminants DDE, pentachlorophenol, DDT, fluorene and pyrene. The exposures were performed with pulses of varying duration and with varying amounts of recovery. The data from some of the compounds showed a delayed toxic effect after removal from single exposures while this did not occur for pentachlorophenol. The data are still being analyzed and manuscripts are expected in the next year. Thus, we did not get as many pulsed exposures performed as hoped because of the amount of time required to address the biotransformation issue.

Publications

Lee, J-H. and Landrum, P.F. Development of a multi-component damage assessment model (MDAM) for time-dependent mixture toxicity with toxicokinetic interactions. Submitted: Environmental Science and Technology

Lee, J-H. and Landrum, P.F. Application of a multi-component damage assessment model (MDAM) for the toxicity of metabolized PAH in *Hyalella azteca*. Submitted: Environmental Science and Technology

Presentations

Lee, J-H. and Landrum, P.F. Development of a multi-component damage assessment model (MDAM) for time-dependent mixture toxicity with toxicokinetic interactions. Society of Environmental Toxicology and Chemistry, Baltimore, November 2005

CA4/IV-13: Changes in Diporeia Populations in the Great Lakes and Lake Champlain

Principal Investigator: Thomas Nalepa, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The benthic amphipod Diporeia is the dominant benthic macroinvertebrate in offshore waters of the Great Lakes and in many glacial lakes of the Nearctic Region. As a detritivore, it ingests organic material settled from the water column (mainly diatoms) and, in turn, is fed upon by most species of fish. Because of this ecosystem role, Diporeia is considered a keystone organism in the movement of energy between trophic levels in these lakes. Recently, densities of Diporeia have declined in Lakes Michigan, Huron, Erie, and Ontario, and large areas are now completely devoid of this organism. While exact causes of the decline in Diporeia are still not clear, in each of the lakes the decline was coincident with the establishment and spread of the zebra mussel, Dreissena polymorpha.

The objective of this research project is to determine if protozoans may be the cause of the disappearance of Diporeia. Potentially, the metabolic activities of mussels (deposition of waste material) may enhance protozoan populations. Preliminary investigations showed that some Diporeia were infested with epibiotic protozoans that could contribute to poor organism health, particularly when they attach to the gills.

Accomplishments

- The relationship between declines in the benthic amphipod *Diporeia* and body burdens of attached epibionts was examined at three sites in southeastern Lake Michigan. Samples were collected on a monthly basis (April to October) in 2002. At the time, *Diporeia* populations at the three sites were in various states of decline. Epibionts associated with 173 specimens of *Diporeia* were

examined using scanning electron microscopy (SEM). Overall, the most frequently occurring epibionts were Peritrichia (Epistylidae and Lagenophryidae) and Suctoria. Mean number of epibionts per individual *Diporeia* ranged from 39 to 300. Despite contrasting trends in *Diporeia* populations at the three sites (severe decline, no decline, severe decline at time of sampling), the number, type, and body location of epibionts found attached to *Diporeia* were generally similar at the three sites. Based on theses findings, it can be concluded that epibionts were not likely the direct cause of declines in *Diporeia* populations.

Publications

Foley, A. J. III, Nalepa, T. F., Walker, G., and McCormick, M. J. 2005. Epibionts associated with the amphipod *Diporeia* spp. in Lake Michigan. Verh. Internat. Verein. Limnol. (in press).

Presentations

Foley, A. J., Nalepa, T. F., and Walker, G. K. 2005. Associated epibiont populations and the decline of *Diporeia* spp. (Amphipoda) from Lake Michigan. 48th Conference on Great Lakes Research, International Association for Great Lakes Research, Ann Arbor, MI. June, 2005.

Significant Interactions.

Dr. Gretchen Messick, Center for Coastal Environmental Health & Biomolecular Research, Oxford, Maryland -- interactions/discussions related to epibionts associated with amphipods.

Dr. Bozena Kiziewicz, Department of General Biology, Medical University, Bialystok, Poland --- interactions concerning fungi attached to amphipods.

Dr. Kevin Keuhn, Department of Biology, Eastern Michigan University, Ypsilanti, MI –discussions concerning fungi attached to amphipods.

Dr. Glenn Walker, Department of Biology, Eastern Michigan University, Ypsilanti , MI – interactions/discussions on the use of SEM and identifying epibionts.

Dr. Igor Dovgal, Department of Biology, Kiev University, Kiev, Russia – identification of suctorians.

CA4/IV-14: Dynamics of Sculpin Fishes Found in Lake Michigan

Principal Investigator: Stephen Brandt, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The goal of this project was to investigate the foraging ecology and food preferences of two benthic fishes common in the Great Lakes: slimy sculpin (*Cottus cognatus*) and deepwater sculpin (*Myoxocephalus thompsonii*). Past studies of prey selection by fishes in the Great Lakes and other systems have focused overwhelmingly on species inhabiting open-water or littoral habitats. Comparatively little research has been done on the prey selection dynamics of obligate benthivores. A clearer understanding of the processes & mechanisms involved in prey selection by benthic fishes is important for effective management of Great Lakes fishes, particularly in light of recent changes in the benthic invertebrate communities of the Great Lakes (e.g., disappearance of *Diporeia*).

In this project, we focused on the influence of prey abundance and prey behavior on prey selection by slimy and deepwater sculpin. Specifically, we asked the following questions:

- How do sculpin diets and food preferences change with variation in prey availability and prey community composition?
- How does diet composition and food preference compare between sculpin species? Are there differences in diet composition and food preference among sculpin size/age groups?
- Are all sculpin prey attacked and captured with equal probability? If not, what prey behaviors are associated with differential prey detection and capture?
- Does prey capture success differ between sculpin species for a given prey type?

To answer these questions, we used a combination of field and laboratory techniques. Two field studies in southeast Lake Michigan, one in 2000-01 and a second in 2002, were used to assess the influence of prey availability on sculpin diet and food preference. In both studies, we measured sculpin diet composition and benthic invertebrate abundance along inshore-offshore transects at 2-3 locations in southeast lake Michigan. This sampling design permitted the comparison of sculpin

diet composition between locations with different invertebrate availabilities while controlling for depth-related variation in invertebrate community composition. In 2002, estimates of sculpin diet composition and invertebrate abundance were used to calculate a selectivity index (a measure of food preference), and the values of this index were compared between two sampling locations with different prey availabilities. During 2002-2003, live sculpin and invertebrates collected from southeast Lake Michigan were used in laboratory experiments designed to explore the behavioral attributes of the sculpin-invertebrate predator-prey interaction. In the experiments, we observed slimy and deepwater sculpin feeding on various invertebrate prey under natural conditions. All experiments were video-taped, and the recordings were used to measure sculpin reaction distance, encounter rates and prey capture success with 2-3 prey types. Approximately 100 experiments were performed with 6 individual slimy sculpin and 10 individual deepwater sculpin.

During this time period, our objectives were to:

- summarize the results from the 2000-01 field study and report the key findings in a peer-reviewed manuscript
- complete the laboratory and data analysis for the 2002 field study
- review the recordings for all laboratory experiments and build data sets for the various behavioral metrics

Accomplishments

- We made significant progress towards achieving the preceding objectives during this period. Key results from the 2000-01 field study were summarized and accepted for publication in *Transactions of the American Fisheries Society*. Laboratory work and data analysis for the 2002 field study have been completed, and preliminary results were presented at the 2005 annual meeting of the International Association of Great Lakes Research. Data from this study are currently being incorporated into a manuscript.
- Analysis of the video-taped recordings of the laboratory experiments is ongoing. Difficulties with a calibration procedure used to convert image coordinates into actual distance units slowed our progress. These difficulties have been resolved, but required numerous, lengthy communications with experts at other universities. Our goal is to finish reviewing the experiments, make all desired measurements, and analyze the resulting data set within the next 2-3 months.

Publications

Hondorp, D.W., S.A. Pothoven, and S.B. Brandt. 2005. Influence of *Diporeia* density on the diet composition, relative abundance, and energy density of planktivorous fishes in southeast Lake Michigan. *Transactions of the American Fisheries Society* 134:588-601.

Madenjian, C.P., D.W. Hondorp, T.J. DeSorcie, and J.D. Holuszko. In Press. Sculpin community dynamics influenced by interactions with non-sculpin fishes. *Journal of Great Lakes Research*.

Presentations

Hondorp, D.W., S.A. Pothoven, S.B. Brandt. 2005. Diet and prey selection of sculpin in southeast Lake Michigan. International Association of Great Lakes Research. May 23-27, 2005. Ann Arbor, MI.

Madenjian, C.P., D.W. Hondorp, T.J. Desorcie, and J.D. Holuszko. 2005. Sculpin community dynamics in Lake Michigan. International Association of Great Lakes Research. May 23-27, 2005. Ann Arbor, MI.

Hondorp, D.W., S.A. Pothoven, S.B. Brandt, and C.P. Madenjian. 2004. Factors influencing habitat selection in Great Lakes Sculpin. 134th Annual Meeting of the American Fisheries Society. Madison, Wisconsin. August 22-26, 2004.

Significant Interactions

In addition to the proposed work, we have teamed with Dr. Charles P. Madenjian at the United States Geological Survey-Great Lakes Science Center to analyze a 30-year data set on sculpin abundance and distribution in Lake Michigan. This collaboration has already produced one presentation and one peer-reviewed article (in *Journal of Great Lakes Research*). We are working on second manuscript that will detail changes in sculpin depth distributions over that 30-year time span.

Student Participation

Darryl W. Hondorp
Ph.D. Candidate; expected completion 11/05.
School of Natural Resources and Environment, University of Michigan
Tentative dissertation title: Diet and food preferences of sculpin in offshore areas of Lake Michigan.

CA4/IV-15: Distribution and Biomass of Dreissenid Mussels in Western Lake Erie

Principal Investigator: Stephen Lozano, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

The trophic structure of Lake Erie has seen dramatic changes over the past 20 years. Lake Erie continues to be the most rapidly changing of the Great Lakes, reflecting the successes of remediation activities and the expression of both ongoing and novel stresses. The most significant events have related to amelioration of carbon and nutrient loadings to the lake. However, establishment of non-native exotic species, particularly dreissenid mussels has resulted in substantial reallocation of biomass and redirection of energy flow. There is increasing evidence that energy flow patterns in Lake Erie have changed to reflect increasing importance of benthic processes to overall trophic functioning. Phenomena typically associated with increasing eutrophication (rising spring total phosphorus concentrations, episodic blooms of blue-green algae, development of extensive filamentous algal mats at shorelines, recurrent hypoxia in the bottom waters of central Lake Erie) are suspected to be either direct or indirect consequences of these altered trophic processes. The energy and nutrient pathways coupling the benthic and pelagic communities of Lake Erie are only partially understood, and few quantitative data on benthic-pelagic coupling exist to validate or calibrate models or to quantify mechanisms and relationships.

The objectives for this project during this time period were:

- Sort and count dreissenids in 70 ponar samples collected in 2002 and 2003
- Measure the biomass of a representative number of dreissenids for determining length-weight relations
- Enter data into an Excel spreadsheet.

Accomplishments

- Ponar samples from 2002 and 2004 at 45 sites in western Lake Erie were processed and counts were entered into an Excel spreadsheet, WLE_Mussels.xls.

- 280 quagga and 293 zebra mussels were measured for lengths and weights. Biomass was calculated for individual mussels and entered into the Excel spreadsheet, WLE_Mussels.xls.

Publications

There were no publications or presentations that used these data this year.

Significant Interactions

In 2003, the Binational Executive Committee of the Parties to the Great Lakes Water Quality Agreement developed a plan for coordinating Great Lakes monitoring efforts. This entailed conducting Lake-specific intensive, multiagency surveillance. Lake Erie was identified for investigation in 2004. In May and June 2004, Canadian and US agencies collected sediments and measured water chemistry at 283 nearshore and offshore locations through cooperative sampling by Environment Canada, Ontario Ministry of the Environment, Ontario Ministry of Natural Resources, NOAA, the USGS, and other cooperators (the Lake Erie Comprehensive Collaborative Study - ECCS). A total of 10 vessels took part in sampling, the majority of which was conducted in May and June. Hard substrates were sampled by divers operating air lift samplers. Soft substrates were sampled with a standard Ponar grab. Ancillary sediment and epipelic algal samples were collected from most soft sediments. These will ultimately be analysed for sediment physical properties and chemical characteristics as well as for contamination by trace metals, organochlorine compounds and chemical of emerging interest.

CA4/IV-16: Development of a Food Web Model (DOVE) to Examine Invasive Species and Indirect Interactions in Great Lakes Food Webs

Principal Investigator: Scott Peacor, Michigan State University

NOAA Strategic Goal 1

Overview and Objectives

Conventional food web models omit phenotypic plasticity and evolutionary history, two features of ecological communities that likely have a large influence in the structure and dynamics of Great Lakes food webs. I, in collaboration with professors at the University of Michigan and Michigan State University, am developing a modeling approach of food webs that allows the incorporation, and examination of the importance, of these features. A computational system, denoted Digital Organisms in a Virtual Ecosystem (DOVE), will use evolutionary algorithms

(developed in computer science) to represent individual organism behavior in an individually based model. Simulated natural selection allows species to evolve, and solve the complex problem of persistence in the presence of multiple tradeoffs. Here we ask for funds to support a graduate student to work on this project. We have 3 main objectives:

- Examine question concerning invasive species. For example, does the history of invasion affect the success rate of new species invasion and consequent impacts?
- Predict the relative contribution of trait-mediated effects resulting from phenotypic responses to predators, including invasive predators, to the net effect of predators on a food web.
- Study how phenotypic plasticity affects general theory.

Accomplishments

- Progress has been reasonable given the nature of the research. Unexpected problems with the original model development software took extra time, but such delays are expected when developing a new computational system. We are also developing more traditional models to compare to our results which will be helpful, but taking time that we had not planned for.

Publications

This project has supported a graduate student, who greatly assisted with this manuscript that is in Review at Nature:
Phenotypic plasticity increases species coexistence by altering fitness surface
Scott D. Peacor, Stefano Allesina, Rick L. Riolo, and Mercedes Pascual.

Presentation

Ecological Society of America, Aug 2005, Montreal CA. Phenotypic-plasticity increases species coexistence by changing the steepness of an adaptive landscape. Peacor, S. D., R. L. Riolo, and M. Pascual

Significant Interactions

I have given several talks and interacted with faculty concerning this project at Michigan State University (Kellogue Biological station and computer science department), the University of Michigan (invited to speak at course on modeling,

SNRE), and the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin, Germany.

Student Participation

The proposal is supporting Katrina Button who is a Masters student in the Fisheries and Wildlife department at Michigan State University.

CA4/IV-17: Forecasting Impacts of Dreissenid Mussels on Harmful Algal Blooms

Principal Investigator: Henry Vanderploeg, Great Lakes Environmental Research Laboratory and Thomas Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

There has been no activity on this account for Fiscal Year 2005 as these funds are meant to provide continuing support for a NRC Postdoctoral Fellow who will begin work on this project December 1, 2005.

CA4/IV-18: Understanding Interactions between Harmful Phytoplankton and Grazers: Variation in Dreissenid Mussel Effects across Nutrient Gradients

Principal Investigator: Henry Vanderploeg, Great Lakes Environmental Research Laboratory and Thomas Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

The frequency and intensity of harmful phytoplankton blooms in the Great Lakes have increased in recent years despite large reductions in nutrient loading. The central goal of this proposal is to understand how nutrients and exotic herbivores (specifically, dreissenid mussels) interact in promoting harmful phytoplankton in the Great Lakes. Our data suggest that the functional relationship between nutrient loading and harmful phytoplankton biomass is very different in habitats invaded by dreissenids relative to uninvaded habitats, because of complex responses by *Microcystis aeruginosa*, a cosmopolitan, toxin-producing cyanobacterium. The work described in this project is in support of a larger funded proposal (from

NSF/EPA/NOAA ECOHAB/2004-STAR-C1) that was organized around 5 focal objectives: 1) determine if the effect of *Dreissena* on *M. aeruginosa* changes direction across a broad gradient of phosphorus loading, 2) identify thresholds in P loading at which *Dreissena*'s effect changes direction, 3) understand mechanisms underlying the interaction between *Dreissena* and *M. aeruginosa*, with the explicit goal of predicting the consequences of changes in nutrient loading on harmful phytoplankton abundance in the Great Lakes, 4) determine the range of applicability of results from inland lakes to the western basin of Lake Erie, 5) determine the extent to which *Dreissena* promotion of *M. aeruginosa* translates into increased levels of cyanobacterial toxin levels in the Great Lakes. These objectives will be addressed with a combination of large-scale *in situ* experimental manipulations of nutrients and *Dreissena* (**objectives 1, 2, 4**), small-scale experimental measurements of *Dreissena* grazing selectivity and nutrient excretion (**objective 3**), development of new mechanistic theory (**objective 3**), and state-of-the art characterization and measurement of cyanobacterial genetics and toxin concentrations in field populations (**objective 5**). The research directly addresses several priority areas of the ECOHAB program including: "developing general understanding of HABs and their relationships to the surrounding environment" (NOAA), "relationships between nutrient loading, HABs and food web dynamics" (EPA), "the ecological bases for bloom formation" (NSF), and the identification of "nutrient loading thresholds" driving HAB development and effects (EPA). Our integrated research program will provide "sound science" via rigorous large- and small-scale experimentation, and specific predictions for the management of nutrient loading to minimize harmful phytoplankton problems in *Dreissena*-invaded habitats. It will also increase general scientific understanding of how nutrients and grazers interact to suppress or promote harmful phytoplankton blooms.

Specifically, we will carry out experimental work in support of objective 3 by measuring *Dreissena* nutrient excretion and grazing selectivity using water from mesocosms (Gull Lake and Lake Erie) and different sites on Lake Erie. In addition we will be "monitoring" nutrient, phytoplankton, and algal toxins in Lake Erie as described in the work statement below. Most of the funding requested is for support of a CILER Research Associate to help with the extensive field and experimental program. We have been notified of funding for three years, and have been given funds for the first year.

Accomplishments

- We began assembling our team, hiring an extremely well-qualified CILER Research Associate, whom we began training. We began to examine

homeostatic filtering and nutrient excretion by dreissenids by using a variety of state of the art tools at different sites in Saginaw Bay and Lake Erie. Particular emphasis was placed on the Maumee region of Lake Erie. We expected this particle-rich area would represent a challenge to any methods, and is the epicenter of *Microcystis* blooms in Lake Erie. We measured filtering, ingestion, of C, N, and P by the mussels as well as their excretion of ammonia and phosphate, and we took sample for C:N:P ratios of the seston and algal composition.

- We performed experiments at the indicated dates and sites:

Date	Mussel species	Site
21 June 2004	Zebra mussel	Lake Erie 6L(offshore middle of western basin)
13 July 2004	Zebra & quagga mussels	Lake Erie 3M (near Maumee Bay)
28 July 2004	Zebra & quagga mussels	Lake Erie 3M
8 August 2004	Zebra & quagga mussels	Lake Erie 3M
23 August 2004	Zebra & quagga mussels	Saginaw Bay Station 5
20 September 2004	Zebra & quagga mussels	Lake Erie 3M

- We managed to capture some interesting conditions with these experiments. First, we were able to examine filtering and nutrient excretion at times when seston was abundant and its quality was high at station 3M, conditions we have never sampled in our previous work. We did experimental work with mussels and seston collected from Saginaw Bay Station 5 on August 23, when there was a *Microcystis* bloom. This was an interesting bloom in that there was much *Microcystis* (the "canopy species") plus and "understory" of edible algae that appeared to be readily ingested by the mussels. We cannot report many details as we have many nutrient and seston samples to analyze. The experiments represented an intense team effort, and we are pleased we `were able to simultaneously measure response of both zebra and quagga mussels in all but one experiment to see if there are cross species differences. We have, however, analyzed mussel filtering results determined from chlorophyll samples. The mussels filtered at nearly identical rates in all experiments except the one during the *Microcystis* bloom. In that experiment, quagga mussels (which are beginning to replace zebra mussels in most areas of the Great Lakes) filtered at a higher rate than zebra mussels. This may have implications to the selective rejection mechanism of bloom promotion.

- We began assembling a collection of *Microcystis aeruginosa* strains and are beginning to experiment with how the mussels handle these strains, and if the mussels can induce changes in toxicity and colony size in these strains.

Presentations

Three presentations were made at the International Association of Great Lakes Research and the American Society of Limnology and Oceanography.

CA4/IV-19: FISH ECOLOGY AND ECOSYSTEM FORECASTING

Principal Investigator: Stephen B. Brandt, Great Lakes Environmental Research Laboratory and Thomas Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

Fishery managers in the Great Lakes and coastal marine systems need to be able to make predictions as they attempt to manage fisheries in ecosystems that are constantly changing. Problems such as habitat loss, eutrophication, nonindigenous species invasions, and climate change all pose challenges to making the predictions that are needed in fishery management scenarios. For example, in the Great Lakes, recent changes in the benthic community, particularly the invasion by *Dreissena* mussels and subsequent decline of *Diporeia*, have been tied to changes in planktivorous fish distribution and abundance. The invasion of the predatory zooplanktors, *Bythotrephes longimanus* and *Cercopagis pengoi* has been linked to changes in fish diet selectivity and zooplankton availability. Changes in forage fish abundance, condition, and distribution is one factor that has been linked to lower condition of predator fish (Pacific salmon *Oncorhynchus* spp., lake trout *Salvelinus namaycush*) in Lake Huron. Changes in lake whitefish *Corgeonus clupeaformis* condition and distribution have been linked to the *Dreissena* invasion and are affecting commercial fishery harvests in Lakes Ontario, Huron, and Michigan. In Lake Erie, declines in productivity and subsequent declines in forage fish abundance may be contributing to low harvests of walleye in the lake. In the Chesapeake Bay, eutrophication and introduced bacteria have affected *Morone* spp. fisheries, and the harmful parasite MSX that is devastating oyster fisheries may be an introduced species.

The objectives of this project are to improve our knowledge and understanding of food web processes and dynamics and their relationship to environmental quality

and living resources in Great Lakes and coastal marine ecosystems with an emphasis on fish ecology. We will apply this knowledge to better understand the causes, effects, and solutions to problems such as eutrophication, hypoxia, toxic contaminants, non-indigenous species invasions, habitat modification, and climatic variations. A comparison across the Chesapeake Bay and Great Lakes will provide further insight.

Accomplishments

Two major steps were made toward accomplishing our goal of understanding food web processes in the Great Lakes.

- First, all data from 2002-04 on alewife energy density dynamics in Lake Michigan was processed and a manuscript has been submitted to *Canadian Journal of Fisheries and Aquatic Sciences*. The results of this study have also been provided to the Great Lakes Fishery Commission on several occasions this year.
- Second, a large scale field study began in the spring 2005 to collect data on the role hypoxia and non-indigenous species play in structuring the central basin Lake Erie food web. Data collected include physical parameters (oxygen, temperature), fish diets, fish distribution, and prey abundance and distribution (benthos, zooplankton). This project is ongoing, but once the current field season and subsequent data analyses are completed, comparisons can be made to the Chesapeake Bay, where hypoxia and non-indigenous species also influence fish distributions and diet. We will also be able to determine whether predictive models for fish responses to non-indigenous species and physical processes such as hypoxia are applicable across systems such as the Great Lakes and estuarine systems.

Publications

Hondorp, D.W., S.A. Pothoven, and S.B. Brandt. 2005. Influence of *Diporeia* density on the diet composition, relative abundance, and energy density of planktivorous fishes in southeast Lake Michigan. *Transactions of the American Fisheries Society* 134:588-601.

Madenjian, C. P., S. A. Pothoven, J. M. Dettmers, and J. D. Holuszko. (submitted). Changes in seasonal energy dynamics of alewife (*Alosa pseudoharengus*) in Lake Michigan after invasion of dreissenid mussels. Canadian Journal of Fisheries and Aquatic Sciences.

Presentations

Pothoven, S. A., Hondorp, D. W., Brandt, S. B., and Nalepa, T. F. Effects of *Diporeia* declines on diet, condition, and abundance of alewife, bloater, and rainbow smelt in Lake Michigan. 134th Annual American Fisheries Society Meeting, August 22-26, 2004. Madison, WI.

Significant Interactions

For the alewife energy density work, we collaborated with Chuck Madenjian (USGS Great Lakes Science Center) and John Dettmers (Illinois Natural History Survey). For the Lake Erie field project, there has been extensive collaboration with researchers from the Ohio Department of Natural Resources, Ontario Ministry of Natural Resources and the New York Department of Environmental Conservation.

Student Participation

Darryl W. Hondorp
Ph.D. Candidate; expected completion 11/05.
School of Natural Resources and Environment, University of Michigan
Tentative dissertation title: Diet and food preferences of sculpin in offshore areas of Lake Michigan.

CA4/IV-20: Diel Spatial Distribution and Prey Selectivity of Alewifes on Zooplankton, *Bythotrephes*, and *Cercopagis*

Principal Investigator: Henry Vanderploeg, Great Lakes Environmental Research Laboratory and Thomas Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

Introduction and establishment of non-indigenous species to ecosystems of Great Lakes has been a serious problem for many decades. While a first wave of invaders (early in the 20th century) were vertebrates (Eschenroder and Burnham-Curtis 1999) and caused top-down disruptions of food webs, in recent years the second wave, featuring invertebrates, has influenced lower food webs. These lower food web disrupters also have affected or are expected to affect fisheries (Shuter and Mason 2001, Vanderploeg et al., in press). Two of these invertebrate invaders, predatory

cladocerans *Cercopagis pengoi* and *Bythotrephes longimanus*, are new or relatively new invaders that are potentially disrupting energy flow from plankton to planktivorous fish.

Cercopagis pengoi, originating from the Ponto-Caspian region, was first observed in the Great Lakes in 1998 in Lake Ontario, where it became an important component of the crustacean zooplankton by September 1999 and spread to nearby inland lakes (Makarewicz et al. 2001). By summer of 1999, it had spread to Lake Michigan (Charlebois et al. 2001, Makarewicz et al. 2001). In Lake Michigan, populations increased during 2000 and 2001, and high concentrations (> 1000 m^{-3}) were found in nearshore areas (Vanderploeg et al., in press). *Cercopagis* was found also in Lake Erie in summer 2001 (T. Therriault and I. Grigorovich, personal communication) and is expected to be an important component of all Great Lakes except Lake Superior (Vanderploeg et al., in press). This invasion pattern seems to parallel that seen for the other cercopagid, the Palearctic *Bythotrephes longimanus* that spread rapidly among the Great Lakes (Lehman and Caceres 1993, Pothoven et al. 2001) as well as many inland lakes (e. g. Yan and Pawson 1997) during the 1980s.

It has been our goal to develop a general model of prey selection and feeding for these cercopagids and to examine whether these cercopagids contribute to a bottleneck for fish recruitment in Lake Michigan. In addition, we hypothesize that adult alewives control *Bythotrephes* populations, mediating competitive and predatory interactions between *Bythotrephes* and *Cercopagis*, and thus indirectly affect the recruitment process in fish such as alewife *Alosa psuedoharengus* and yellow perch *Perca flavescens*.

Our objectives are to evaluate the impact of yearling and adult alewife predation on *Bythotrephes* and *Cercopagis*. To do this, we need information on zooplankton abundance and vertical distribution (including the cercopagids), alewife abundance, distribution, food habits, and food consumption during both night and day.

Accomplishments

- Two cruises on Lake Michigan near Muskegon, Michigan were completed in August 2004. Bottom and midwater trawling, acoustics (120 kHz), Plankton Survey System, and zooplankton net tows were all used to sample fish and zooplankton. Sampling took place at a nearshore (10 m) and offshore (60 m) site. Alewife were unusually concentrated in the nearshore area and few fish were caught in the offshore area. However, alewife were collected every four hours in the nearshore area during both trips and we were able to quantify

diets and daily ration for adult and yearling alewives. A total of 653 alewives were examined for diet analysis and daily ration calculations.

- All laboratory work on alewives was completed. Both *Bythotrephes* and *Cercopagis* were present during at least some of the sampling times for each date. The fish and zooplankton data that were collected will be adequate to quantify the role alewife planktivory plays in structuring *Bythotrephes* and *Cercopagis* populations in nearshore areas. We had anticipated sampling in a transitional area (45 m), but large quantities of dreissenid mussels in the area prevented effective sampling of fish. Most planktivorous fish in the nearshore were alewife, but spottail shiners *Notropis hudsonius* were also abundant at night. Other species will be examined if deemed necessary. Diet selectivity will be calculated once zooplankton counts are finished.
- Work is underway on additional data summaries and manuscript preparation.

Significant Interactions

We are working with Chuck Madenjian, Robert O'Gorman, and Jeff Schaeffer of the USGS Great Lakes Science Center to put our intensive work in one area of Lake Michigan into a wider context of the Great Lakes.

CA4/IV-21: Assessment of Cyanobacterial Blooms and Microcystin Concentrations in the Great Lakes

Principal Investigator: David Millie, Florida Institute of Oceanography, University of South Florida-Bayboro and Thomas Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

Bloom-forming, toxic cyanobacteria occur worldwide in nutrient-enriched freshwaters, including the Laurentian Great Lakes. Blooms have disastrous short term and long term consequences for water quality and resource utilization. In particular, cyanobacterial toxins are noted causative agents for human and animal illness/mortality as well as a litany of environmental-, legal-, and recreational-related problems. *Microcystis aeruginosa*, the dominant bloom-forming, toxic cyanobacterium occurring throughout the Great Lakes, produces a suite of monocyclic hetapeptide peptide hepatotoxins, known as microcystins - the most important of which is microcystin-LR. *Microcystis* has (again) become a dominant

component of the summer phytoplankton in both Saginaw Bay and western Lake Erie, after being a relatively minor component during the late 1980s and early 1990s. Moreover, microcystin concentrations exceeding the recommended limit of 1 μg L^{-1} for drinking water (World Health Organization 1998) recently have been verified in both systems. Accordingly, the recent expansive blooms of *Microcystis* and corresponding microcystin concentrations have caused considerable concern in regard to the sustainability of natural resources and human health.

Dr. Millie's work is being conducted as a component of and in collaboration with research activities of the *Center for Great Lakes & Human Health* (under administrative auspices of the National Oceanic & Atmospheric Administration's [NOAA] Great Lakes Environmental Research Laboratory; Ann Arbor, MI). Dr. Millie is a co-Principal Investigator of the Harmful Algae & Toxin Research Group (with Drs. G. Fahnenstiel, J. Dyble, P. Tester, & W. Litaker) assessing cyanobacterial blooms and microcystin concentrations for the Center throughout Saginaw Bay and western Lake Erie, 2004-2009.

In this initial year of the project (2004-2005), the main objectives for were to determine spatial distributions of *Microcystis* abundance and microcystin concentrations throughout Saginaw Bay and western Lake Erie.

Accomplishments

During a research cruise onboard the R/V Laurentian in August 2004, a series of transects across Saginaw Bay and western Lake Erie were completed with samples collected for analysis of chlorophyll *a*, photopigment-derived estimates of phytoplankton community structure, nutrients, primary production, carbon-specific growth rates, microcystin toxin concentrations, cell counts and genetic analysis (of the *Microcystis* component).

In D. Millie's contribution to the project, specific accomplishments from 7/2004-6/2005 include:

- Sample extraction and HPLC-based analytical protocols for microcystins were identified and perfected using toxin standards (obtained commercially) and extra-/intra-cellular bloom samples. Sample analysis/data interpretation is continuing.
- Photopigments (for determination of community structure) were extracted and analyzed via HPLC-methodology. Data analysis/interpretation is continuing.

- Samples for carbon-specific growth have been extracted and analyzed (via HPLC- & liquid scintillation-methodology. Data analysis/interpretation is continuing.
- *Microcystis* colonies were isolated for (future) culture experiments.
- Developmental work and validation for surface-enhanced laser desorption ionization - time of flight mass spectrometry (SELDI-TOF) characterization of microcystins completed (see Additional Planned Work, below).
- Phytoplankton abundance, as chlorophyll *a* concentrations, throughout Saginaw Bay was modeled from candidate physical/chemical (predictor) variables. Using a six-year data set (collected by GLERL researchers, 1991-1996), networks successfully reproduced the intrinsic variance and magnitude of chlorophyll *a* dynamics (see technology transfer, below).

Preliminary Findings

- The cyanobacterial community in Saginaw Bay was predominantly composed of *Microcystis* spp. and *Anacystis* sp. (another small colonial, but non-toxic taxon). The cyanobacterial community within Lake Erie was dominated by *Microcystis* spp.
- Maps of intra- and extra-cellular microcystin concentrations throughout Saginaw Bay and western Lake Erie were completed (see paper presentations, below) . Intracellular microcystin concentrations ranging to 3.5 μg/L were observed in Saginaw Bay whereas intracellular concentrations ranging to 1.7 μg/L were observed in Lake Erie. In both systems, the greatest concentrations were observed nearshore. Extracellular concentrations were considerably less than intracellular concentrations, ranging from 0.18 μg/L (Saginaw Bay) to 0.38 μg/L (Lake Erie). An intracellular concentration of 58 μg/L was observed within a surface scum entrapped within an inlet on the north shore of South Bass Island.
- The presence/magnitude of microcystin concentrations did not always correspond to the occurrence of *Microcystis* – molecular work (by Dr. J. Dyble) indicates that toxic- and non-toxic strains of *Microcystis* are present in both systems

Publications

Millie, D. F., Weckman, G. R., Pigg, R. J., Tester, P. A., Dyble, J., Litaker, R. W., Carrick. H. J., & Fahnenstiel, G. L. In final draft; to be submitted 7/05

(tentatively, the *Journal of Phycology*). Using artificial neural networks to model phytoplankton abundance and discern functional impacts of environmental variables in Saginaw Bay, Lake Huron (USA).

D. Millie, B. Gregson, D. Fries, R. Pigg, G. Fahnenstiel, & J. Dyble. In preparation. Enhanced detection and determination of cyanobacterial toxins: uniting microcystin 'capture' on immunoreactive surfaces with surface-enhanced laser desorption/ionization time-of-flight mass spectrometry. To be completed 2005. (journal undecided).

Presentations

Modeling Phytoplankton Biomass in Saginaw Bay, Lake Huron using Artificial Neural Networks. D. Millie, G. Weckman, R. Pigg, H. Carrick, P. Tester, J. Dyble, W. Litaker, & G. Fahnenstiel. Oral presentation – 2005 International Association of Great Lakes Research Annual Meeting; Ann Arbor, MI (May, 2005)

Microcystin concentrations and genetic diversity of Microcystis in Saginaw Bay and western Lake Erie. J. Dyble, P. Tester, W. Litaker, G. Fahnenstiel, & D. Millie. Poster presentation – International Association of Great Lakes Research Annual Meeting; Ann Arbor, MI (May, 2005)

Assessment of microcystins using surface-enhanced laser desorption/ionization time-of-flight mass spectrometry. D. Millie, B. Gregson, D. Fries, R. Pigg, G. Fahnenstiel, P. Tester, J. Dyble, & W. Litaker – abstract submitted, intended presentation at *Third Symposium on Harmful Marine Algae in the U.S.*(Monterey, CA; October 2005).

REMOTE SENSING OF LARGE LAKE AND COASTAL OCEAN DYNAMICS

Remotely sensed environmental data for near real-time observation of the Great Lakes support a variety of research activities and resource management needs. For example, the rapid formation and extensive existence of ice throughout the Great Lakes basin creates a serious need to more fully utilize the capabilities of remote sensing to foster and promote safe navigation. Furthermore, the well-developed methods of terrestrial remote sensing provide excellent mechanism from which to analyze change brought about by society, environmental conditions, and land-water interactions. These capabilities utilized in a data fusion framework will provide the catalyst for the formation of the next generation of numerical predictive models for Great Lakes and coastal ocean dynamics.

CA4/V-02: COASTWATCH OPERATIONS

Principal Investigator: George A. Leshkevich, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

CoastWatch is a nationwide National Oceanic and Atmospheric Administration (NOAA) program within which the Great Lakes Environmental Research Laboratory (GLERL) functions as the Great Lakes regional node. In this capacity, GLERL obtains, produces, and delivers environmental data and products for near real-time observation of the Great Lakes to support environmental science, decision making, and supporting research. This is achieved by providing Internet access to near real-time and retrospective satellite observations, in-situ Great Lakes data, and derived products to Federal, state, and local agencies, academic institutions, and the public via the Great Lakes CoastWatch web site (http://coastwatch.glerl.noaa.gov). The goals and objectives of the CoastWatch Great Lakes Program directly support NOAA's statutory responsibilities in estuarine and marine science, living marine resource protection, and ecosystem monitoring and management. Great Lakes CoastWatch data are used in a variety of ways including monitoring of algal blooms, plumes, ice cover, and water temperatures, two and three dimensional modeling of Great Lakes physical parameters (such as wave height and currents), damage assessment modeling, research, and for educational and recreational activities.

This project focuses on research and applications development utilizing CoastWatch imagery and imagery from new satellite sensors such as synthetic aperture radar (SAR) for ice classification and mapping and ocean color sensors such as the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) and/or MODIS for ocean color (chlorophyll) products. These products will enhance the CoastWatch Great Lakes product suite by developing regional products and applications for the Great Lakes, and will contribute to the operational responsibilities of sister agency's such as the U.S. Coast Guard and National Weather Service. One of the objectives of the CoastWatch Great Lakes program is to provide access to near real-time and retrospective (two weeks) satellite observations and derived products of the Great Lakes for Federal, state and local decision making, supporting research and public use. Communications requirements and data distribution are accomplished electronically via the Internet.

Accomplishments

- Maintain and improve web site for data/product availability and distribution:
  - reprogram to receive and handle HDF file format (complete)
  - convert image format to include 1024 x 1024 format (complete)
  - display and distribute AVHRR imagery in PNG and GeoTiff formats - both 1024 x 1024 synoptic and 512 x 512 regional scenes (complete)
  - obtain/install dedicated web server (complete)
  - obtain/install new image/map server (ArcIMS will be installed and tested) (complete)

- Expand/Enhance Product Suite:
  - reformat GLSEA SST composite chart to 1024 x 1024 and implement new compositing scheme (in progress – working around schedules of other participants)
  - improve turbidity product (in progress-working around schedules of other participants)
  - implement MODIS true color high resolution (250 m) imagery (complete).

Publications

Leshkevich, G.A. and S. Liu. 2003. Environmental Monitoring of the Great Lakes Using CoastWatch Data and JAVA GIS. Backscatter. Alliance for Marine Remote Sensing Association, pg.13-16.

Presentations

Leshkevich, G.A. and S. Liu. Great Lakes CoastWatch Program Update - 2005. Technical Meeting, Eastern Great Lakes Region/American Society of Photogrammetry and Remote Sensing, Ludington, MI, Aug. 19, 2005.

Significant Interactions

On the Great Lakes CoastWatch web site (http://coastwatch.glerl.noaa.gov) users have access to CoastWatch near real-time AVHRR satellite image data and products. During the period July 1, 2004 through June 30, 2005, the web site was visited 265,138 times and the total number of pages viewed was 1,136,759.

Participated in the development and implementation of the Great Lakes Observing System (GLOS) - working with the GLOS development team.

MARINE ENVIRONMENTAL ENGINEERING

The Great Lakes and coastal waterways of the United States have been threatened in recent times by many invasive (non-indigenous) species. The primary mode of introduction and transport of these foreign invaders resides in marine vehicles, structures and systems, associated with the water-bore segment of world trade. In addition, mechanisms for the handling of contaminated sediments, dredge spoils as well as accurate and automated methods of providing safe navigation are expected to provide many difficult technical problems related to the marine environment. As new problems are discovered, innovative and revolutionary marine environmental engineering solutions will be required. Research by CILER Fellows in this task includes engineering related to the design and production of a wide variety of vehicles, structures, and systems to operate successfully in the harsh and demanding marine environment and also includes engineering which supports the understanding and proper use of the marine environment.

CA4/VI-02: BIOLOGICAL CHARACTERIZATION AND ASSESSMENT OF ANS INVASION RISK FROM NOBOB VESSELS

Principal Investigators: Gary L. Fahnenstiel, Great Lakes Environmental Research Laboratory; Thomas H. Johengen, University of Michigan and David F. Reid, Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

Global shipping moves roughly 80 percent of the world's commodities and is fundamental to world trade. As an unintended result of these shipping activities, numerous cases of nonindigenous species introductions have occurred worldwide. In total, 159 successful exotic species invasions have been documented in the Great Lakes, and 41 of these introductions are believed to have resulted from shipping activities. Furthermore, the rate of introductions has increased dramatically during the past few decades, with six new introductions occurring between 1984 and 1990 alone. While invasive species of phytoplankton have not received the attention of many other macroscopic species, they nonetheless still may be a significant concern. For example, 23 phytoplankton species have been introduced to the Great Lakes via shipping activities and large populations of one of these, *Stephanodiscus binderanus*, have caused significant water quality (taste and odor) problems in municipal water treatment facilities. Moreover, successful introduction of non-indigenous

phytoplankton into the Great Lakes has contributed to the extirpation of native species via competition, a result with ramifications for the base of the food web.

While circumstances vary from ship to ship, the relatively small amount of water that remains in most NOBOB (NO Ballast On Board) vessels entering the Great Lakes, together with any residual sediment, potentially harbors nonindigenous organisms. Consider a tank holding 1500 metric tonnes of water when full. If only one percent of that volume is unpumpable, then up to 15 metric tonnes of water would remain. Reflected across the numerous tanks each ship possesses, a significant tonnage of ballast water can remain on board. Indeed, a 1991 Canadian study of NOBOB vessels entering the seaway reported volumes of ballast residuals ranging from 59 to 468 tonnes, with an average of 158 tonnes. It is this phenomenon that makes critical our better understanding of NOBOB vessel operations on the Great Lakes. Concerns about NOBOB biopollution have risen from a position of relative obscurity a few years ago to one of the chief environmental concerns in the Great Lakes basin today. On average, less than 15 percent of the ocean vessels entering the Great Lakes contain declarable ballast water on board. In 1996, for example, of 538 ocean entries, only 38 (6.1 percent) were vessels "in ballast" and thus subject to ballast water exchange requirements. NOBOB vessels escape regulation under existing U.S. and Canadian federal, state, and provincial laws, yet their ballast tanks may retain residual volumes of unpumpable ballast water and may contain an accumulation of sediment representing numerous previous ballasting operations.

Considering that NOBOB ships now constitute the bulk of commercial ship traffic entering the Great Lakes, we proposed to examine the possibility of invasions associated with their residual ballast water and sediment. We evaluated the risk of invasions associated with ocean-going vessels entering the Great Lakes. Specifically, two interrelated objectives were addressed:

- Characterize phytoplankton communities present in NOBOB tanks.
- Measure the effect of adding Great Lakes water as ballast to NOBOB tanks on germination and growth of nonindigenous phytoplankton species present in ballast residuals and on their potential release from ballast tanks.

Accomplishments

- Analyses of phytoplankton abundance and growth potential were completed for all samples collected in 2001 and 2002 including 55 wet sediment samples and two dry sediment samples. Dinoflagellate cyst represented zero to 80

percent of total between phytoplankton abundance (average = 24 percent). Almost all the samples contained at least one dinoflagellate species, with a maximum 13 species. A total of 35 cysts species were identified, and 20 species were repeatedly found in both years. Twenty five percent of these species are reported to be toxic species, and a PSP causing species *Alexandrium minutum* is the most common species which occurring in 33 percent our samples. All the dinoflagellate cysts identified in our study are non-indigenous, including at least three species that are common members of the Baltic Sea flora. Dinoflagellate cyst species were found less in flushed tanks than in non-flushed tanks. Further study of the relationship between cyst composition and management practices may help to identify a protocol for monitoring the efficiency of management practice.

- Germination and growth experiments were completed for samples collected in 2001 and 2002, including 33 water samples and 57 sediment samples. Experiments were performed using four different freshwater and one saltwater culture media. In all experiments at least one of the freshwater treatments produced phytoplankton growth from the residual material. However, there was tremendous variability in the growth potential of each sample among treatments, both in absolute response and the dominance of species.
- Diatoms were found to be the dominant species in almost all growth experiments. Twenty-five species of non-indigenous marine and freshwater diatoms have been identified from the 20001 samples. Germination of non-indigenous species was found in 50 percent of samples; most of these species (50 percent) can grow in Lake Michigan or Grand River water, indicating the potential for ballast tank residuals to be a source of viable non-indigenous phytoplankton species to the Great Lakes. Several non-indigenous species were found to grow in both freshwater and saltwater culture media, indicating their potential viability in ocean water exchange treatment.
- A total of five different vessel voyages were examined for objective 2, one in each 2001 and 2002, and three in 2003. Germination experiments were completed for all of the samples from these voyages. Experiments were performed using freshwater culture medium (GL) and Lake Michigan water. Phytoplankton growth was minimum in Lake Michigan water, but growth was significant in GL medium. There was significant variability in the growth potential of samples collected from the harbor water where ships were ballasting and ballast samples taken at the initial and final time points of the voyages. Phytoplankton growth was significantly higher in final

ballast samples than in the harbor water sample for the 2001 experiment. Furthermore, there were no marines species observed in the harbor and initial samples, but marine species accounted for about one percent in the final sample. For the 2002 trial, the growth of phytoplankton was similar between initial and final sampling time points. For the 2003 trials, growth was significantly different between harbor water, T_0 ballast sample, and T_f ballast sample. The species composition analysis from these trials is under process.

Publications

Currently two publications are in the final stages of development. None in press.

Presentations

Johengen, T.H., D.F. Reid, P.T. Jenkins, S.A. Bailey, C.D.A. van Overdijk and S.A. Constant. 2003. Assessment of NOBOB ballast tank residual as a potential vector of ANS: a summary of field activities and chemical conditions within the tanks. Joint International Association for Great Lakes Research/ International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Reid, D.F., S.A. Bailey, T.H. Johengen, S.A. Constant, P.T. Jenkins, C.D.A. van Overdijk, I.C. Duggan and H.J. MacIsaac, 2003. NOBOB project task 2: ballast tank mesocosm experiments and use of incubator-emergence traps. Joint International Association for Great Lakes Research/International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Hong, Y., G.L. Fahnenstiel and R. Stone R. 2003. Dinoflagellate cysts in NOBOB ballast tank sediment: potential risk of invasion to the Great Lakes. Joint International Association for Great Lakes Research/International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Fahnenstiel, G. 2002. NOBOB vessels as vectors of non-indigenous phytoplankton in the Great Lakes. Winter ASLO Meeting. February 11-15. Honolulu, Hawaii.

Significant Interactions

This project was funded by multiple sponsors that included the U.S. Coast Guard, NOAA, and U.S. EPA. In addition, the activities conducted within this project led to the development of a successfully funded research proposal submitted to the Great Lakes Protection Fund. These additional funds allowed us to extend the scope of

work, increase the number of vessels sampled, and increase the breadth of analyses conducted on ballast tank residuals. This project involves the collaboration of researchers from GLERL, the University of Michigan, the University of Windsor, and Old Dominion University. Results described here represent activities completed under the supplemental project as well as the cooperative agreement project.

Student Participation

There were no students working directly on this component of the study.

CA4/VI-05: Evaluating Aspects of the Ballast Tank Vector for Nonindigenous Species in the Great Lakes

Principal Investigator: David Reid, NOAA/Great Lakes Environmental Research Laboratory and Thomas H. Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

The ballast tanks of commercial vessels are the primary vector for transporting aquatic invasive species (AIS) between coastal ecosystems. NOAA has responsibilities under Public Law 101-636 as amended through October 1996 to carry out programs and research to prevent the introduction of invasive species to coastal ecosystems of the United States. NOAA's Ballast Treatment Technology Demonstration Program is designed to explore alternative ballast treatment approaches aimed at eliminating or reducing the invasive species risk associated with ballast water and ballast tanks.

At present, ballast treatment approaches being tested by various groups in the United States and elsewhere fall into categories of physical removal (filtration; hydrocyclone or ultracentrifuge) and/or some form of biocide exposure (UV radiation, heat, ozonation, deoxygenation, and various chemical biocides). However, most tests of various treatment technologies and approaches have looked only at pelagic organisms, which will likely be the most easily treated. Resting stages, which may be sucked in from local sediments with incoming ballast water or produced by organisms entrained with the ballast water, have generally been ignored. The Great Lakes NOBOB (no-ballast-on-board) Program sampled the residual ballast material in 82 ballast tanks over the 2001-2002 Great Lakes shipping seasons. All residual samples contained varying concentrations of viable invertebrate resting eggs, ranging from 10^5 to 10^6 viable eggs m^{-2} of residual sediment. Based on these results,

resting eggs pose a potential invasion threat to both marine coastal areas and the Great Lakes. While various treatments are being developed and tested for removing or killing organisms in ballast water, resting stages have generally been overlooked, and due to their size range, will be difficult to physically remove from an incoming ballast water stream.

Coulatti et al (2003) summarized available overseas vessel traffic statistics for the Great Lakes for the period 1978-2000. However, they did not obtain any direct information about ballasting practices off these vessels while in the Great Lakes, and also had to make assumptions in order to classify each ship as either ballasted or NOBOB. Coast Guard records from 1991 through 1997 are now available that can be used to check the classifications assigned by Coulatti for ships entering during those years. In addition, the Great Lakes Environmental Research Laboratory is collecting ballast intake and discharge data from ships operating in the Great Lakes during the 2003 shipping season. These new data can be correlated and compared to the Coulatti database. Doing so will improve the accuracy of our understanding of vessel traffic and ballast patterns in the Great Lakes.

The objectives of this project were to:

- Test the effect of various biocide treatments on the viability of a variety of zooplankton resting eggs obtained from natural populations, laboratory cultures, and ships of opportunity.
- Update, correlate, and re-evaluate existing data on the entry and ballasting characteristics of commercial vessels while in the Great Lakes.

Research Plan

Resting eggs will be separated from sediment and sorted into appropriate groupings for replicate control and exposure test sets. Control sets will be exposed to optimum hatching conditions as determined by a combination of procedures outlined by Bailey et al (2003) and Landrum (pers. comm., NOAA Ballast Water Technology Project, "Disinfection of ballast water with chemical disinfectants."), and other appropriate literature sources. The hatching success of replicate egg sets under optimized laboratory conditions will be compared against hatching success under similar optimum conditions but with exposure to different biocides (chlorination, SeaKleen™, glutaraldehyde, heat, anoxia) at various concentrations or doses. Two series of tests will be conducted for chemical exposures: one using eggs separated from sediment and placed in aqueous culture media, and one in which the eggs are gently mixed into a known sediment matrix which is then covered with aqueous

culture media, the latter to explore the biocide effectiveness in the presence of sediments, as found in the bottom of many ballast tanks.

Ballast Reporting Forms for each year from 1991 through 1997, obtained from U.S. Coast Guard archives, will be examined and information extracted for addition to the Vessel Traffic Database obtained from R. Coulatti (University of Windsor). The database will be updated and corrected, and the frequency of misclassification of vessels as NOBOBs will be determined. Ballast Surveys data will be analyzed for ballast intake and discharge amounts, frequency, and locations, while the vessels operate in the Great Lakes.

Accomplishments

- Significant progress has been made in developing sampling and laboratory protocols to conduct the toxicity experiments. However, progress has been slowed by the inconsistencies in finding viable resting eggs from the various sediments that we have sampled. Egg densities were often not sufficient species composition varied to greatly to meet our preferred experimental design. The following tasks have been completed:
  - Obtained sediment from Lake Michigan and Muskegon Lake.
  - Obtained sediment from various ship ballast tanks of opportunity.
  - Obtained sediment from Lake Erie.
  - Cultured various species of lake zooplankton in laboratory.
  - Extracted resting eggs from sediments.
  - Induced resting egg production in laboratory cultures.
  - Purchased resting eggs from commercial sources.
  - Created new methods to apply standard ecotoxicological protocols to resting eggs.
  - Conducted bioassays testing the acute toxicity of SeaKleen on the resting eggs of rotifers, copepods, cladocerans, and brine shrimp.
- As of November 2004, the Seaway has reported a total of 815 vessels upbound to the Lakes during the 2003 and 2004 shipping season. To date we have received 216 surveys from participating vessels, for a survey return rate of 26.5%. However, the number of responses will increase as surveys may be received up to two months past the 2004 winter closing of the Seaway. Approximately 10 percent of the vessels reporting declared having at least some ballast on board, and 90% of the vessels declared No-ballast-on-Board (NOBOB). These percentages are consistent with the vessel traffic patterns

observed during the past decade or so, and continue to point to the importance of understanding to what extent ballast operations of NOBOBs trading within the Great Lakes pose a risk for introduction nonindigenous species.

- Ships entering the Great Lakes were found to have traded from a variety of countries prior to entering the Great Lakes (Fig. 1). Each of these countries represents a potential donor region for new nonindigenous species introductions. Western Europe was the predominant region from which ships made their last port of call (typically loading cargo for trade within the Great Lakes) prior to entering the Great Lakes (Fig. 2).

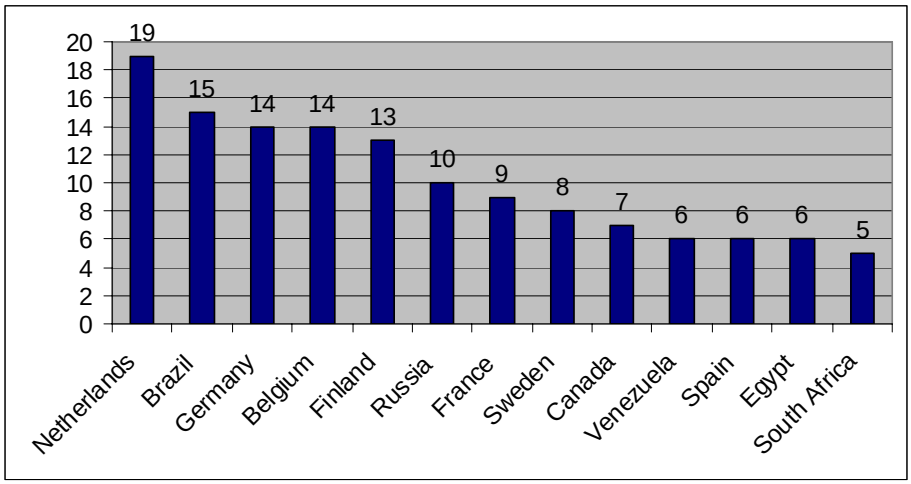


Figure 1. Countries visited by foreign vessels prior to their arrival and trade in the Great Lakes.

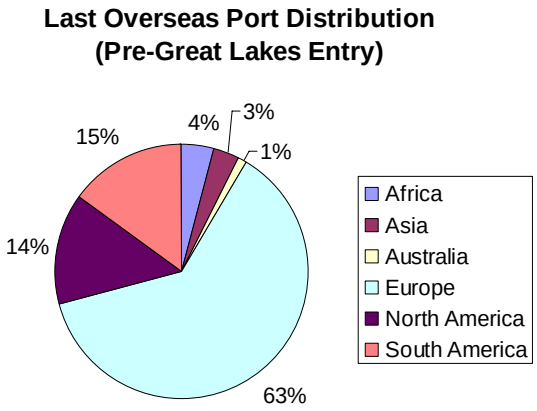


Figure 2. Last Overseas port of call prior to entering the Great Lakes.

Publications

none

Presentations

Raikow, David. 2004. Biological Invasion in the Great Lakes: Science, Management and Policy", Invited Seminar, Purdue University.

Reid, David. 2004. Results from the survey study were presented to the US Coast Guard at the Great Lakes Marine Community Day, January. Cleveland, Ohio.

Significant Interactions

USGS Great Lakes Science Center - sediment collected in the Western Basin of Lake Erie provided by Don Schlosser. University of Toledo Lake Erie Center - sediment collected in the Western Basin of Lake Erie provided by Tom Bridgeman. University of Windsor - visited lab and observed sediment handling and egg extraction techniques. Purdue University - visited lab of Chip Blatchley, with whom we are collaborating to test toxicity of UV light.

Student Participation

The project supported one Great Lakes summer fellow who spent 3 months this past summer working on the resting egg component of the project.

CA4/VI-06: IMPROVING UNDERWATER RESEARCH

Principal Investigator: Guy Meadows, School of Naval Architecture and Marine Engineering, University of Michigan and Thomas H. Johengen, University of Michigan

NOAA Strategic Goal 1

Overview and Objectives

The Seabotix LBV 150 Mini ROV (Remote Operated Vehicle), is a small submersible vehicle remotely controlled through an umbilical by an operator located above the water surface. As well as the standard equipment, the vehicle is equipped with an enhanced external lighting system, a remote operated "hand" with opposing jaws for grasping, a Tritech Micron Ultra Compact Imaging Sonar, and an integrated console which combines the power supply, control console and LCD Monitor in one pelican case.

Accomplishments

- During summer 2005, the Mini ROV has been used in conjunction with the New University Research Initiative. This is a university exchange program offered to a group of Korean students from Mokpo University that immerses the students in American culture while engaging them in engineering academic activities. Thirteen students were tasked with building a small, low cost ROV from off the shelf parts, as part of this learning experience, the students were all trained on the operation of the Mini-ROV in our towing tank facility. The culmination of this project took the students to the NOAA Thunder Bay National Marine Sanctuary and Underwater Preserve to pilot the Mini-ROV on expeditions to several of the shipwrecks that are located in Thunder Bay near Alpena, MI.
- This fall (2005) the Mini-ROV was used to investigate the wreck of the Cornelia B. Windiate for The History Channel's Deep Sea Detective Series. The Cornelia B. Windiate is a shipwreck in pristine condition located in the Thunder Bay National Marine Sanctuary and Underwater Preserve. The Mini-ROV's small size and advanced controlling systems allowed it to penetrate areas of the shipwreck that had never previously been explored.
- The Mini-ROVER was also made available to the public and visiting dignitaries as part of the inaugural celebrations at the grand opening of the NOAA Thunder Bay National Marine Sanctuary and Underwater Preserve. The event was well attended by hundreds of visitors including the local and regional community, several middle school and high schools, researchers as

well as many government officials including members of congress and the senate.

- As well as the above mentioned activities, the Mini-ROV has been available to the local and state law enforcement agencies to assist with deep and /or dangerous activities, the Mini-ROV trained with the Michigan State Police Underwater Recovery Unit for 3 days in a frozen northern Michigan lake. The ROV has two, high resolution video cameras, advance SONAR capabilities for searching large areas where known targets may exist, and a small grabber for retrieving evidence or delivering tools.

CA4/VI-07: NOBOB BEST MANAGEMENT PRACTICES

Principal Investigator: Thomas H. Johengen, University of Michigan and David Reid, NOAA/Great Lakes Environmental Research Laboratory

NOAA Strategic Goal 1

Overview and Objectives

We proposed a scientific study to 1) test and evaluate the effectiveness of the current BMPs, focusing on a subset that are specifically applicable to ballast management for invasion risk reduction of empty (NOBOB) ballast tanks on ships entering the Great Lakes, and 2) test a set of enhancements to the existing BMPs based on results from our Great Lakes NOBOB Assessment study. The enhancements add the following new or modified practices: 1) when in locations that appear undesirable for ballasting use the minimum possible ballast in the fewest tanks possible and complete ballasting after transit out of the undesirable conditions; 2) when carrying ballast, discharge and replace poor quality ballast water with cleaner water as soon as possible to minimize the amount of sediment accumulation; and 3) regularly perform a saltwater flush of all empty (NOBOB) ballast tanks when transiting the ocean.

We have developed the following three interrelated Tasks to accomplish our stated goals and objectives:

Task 1: Assess the effectiveness of specific ballast management practices on sediment accumulation and characteristics within ballast tanks.

Task 2: Assess the effectiveness of specific ballast management practices to reduce the density and viability of organisms and resting stages.

Task 3: Characterize source invertebrate populations and assess salinity toxicity as a barrier to prevent transfers of "high risk" species to the Great Lakes in ballast tanks.

Project Difficulties and Modifications

Based on our ongoing interactions with Polsteam Shipping Lines it became apparent that we would be best served to modify our original plan of working with a single vessel over just the 2004 shipping season. These modifications were deemed necessary due to unexpected changes in the shipping schedule of the ship that we had selected to work with. First there was a significant delay in initiation of the selected ship trading in the Great Lakes. Secondly it appeared highly likely that there would be a reduced number of repeat visits into the Great Lakes by any one ship. The current strategy that we developed to minimize these impacts is to work with multiple ships (but only two at a time) and to plan for extending our field program through 2005. On each of the participating ships we designate and sample only 1 treatment and 1 control ballast tank, therefore, the total number of tanks to sample and instrument remained the same as specified in the proposal. We feel this new approach will provide the best set of observations and increase the likelihood that we capture a variety of ballast management practices. An additional modification is that we have been targeting other ships that we have previously worked with in the NOBOB Assessment project to conduct emergence trap experiments detailed in Objective 2.4.

Accomplishments

- In March and April 2004 we purchased and assemble the mulit-parameter water quality probes and the GPS tracking system that we used to complete activities identified under Task 1 of the proposal. We have assembled and calibrated 5 monitoring probes and 2 GPS units. One probe was deployed in each of the 4 tanks used in the study. The fifth probe was used by the ship's crew to measure ambient water quality conditions in each port where the designated tanks will be ballasted. All probes were configured to measure and record temperature, conductivity (salinity), dissolved-oxygen, turbidity, and chlorophyll-a. Times and locations of all reading were synchronized using the logged data recorded by the GPS unit.
- We completed the initial sampling of the first vessel on July 29-30, 2004. In each of two ballast tanks, we surveyed 40 floor area's evenly distributed throughout the tank to capture regions close and far from the bellmouth as well as regions near mid-ship and out to the turn-of-the-bilge. For 20 of the

floor areas we made detailed maps of the current area and depth of sediment, and captured a photographic record of the area. The maps will be used comparatively on each sampling event to note accumulation or movement of the residual sediment. In the remaining 20 floor areas we completely removed all existing sediment so that we could make a more accurate assessment of the quantities of material that accumulate between successive sampling events. This sampling strategy will hopefully allow us to examine sediment accumulation onto bare surfaces and as sediment accumulating on top of existing residual material which represents the more typical condition.

During this sampling trip, one monitoring probe (Fig 1) was deployed in both the treatment and control tanks. The probes were placed in similar cell areas near the intake/discharge port (bellmouth) in each of the two ballast tanks to record the characteristics of the incoming and discharging ballast water within the tanks. The probes were put into logging mode just prior to their installation and are programmed to log at 30-minute intervals. In addition, we mounted the GPS unit on top of the bridge and it is programmed to log time and position at 15- minute intervals. The time stamps on the probes and GPS unit were synchronized prior to the deployment. The data from these instruments will be used for comparison with and verification of ballast event records kept by the ship and measurements of sediment accumulation.

Figure 1. Multi-parameter water quality monitoring probe.

- Lastly, we developed a detailed ballasting log and have worked with the Master and Chief Officer to ensure that it will be probably completed. Information from the logs and the instruments will be retrieved upon each subsequent sampling of the ship.
- Additional funding was developed for the project with the USCG and NOAA in order to purchase 4 additional YSI sondes and to upgrade 4 In-Situ sondes. These instruments were all assembled and brought on line during the first part of 2005. So we are currently operating eight YSI 6600 EDS sondes and

four In Situ sondes. These instrumented have been distributed among two operating ships, the Lady Hamilton and the IRMA. On the IRMA we have 1 instruments each in two ballast tanks, one to serve as a control and one to operate as a 'treatment' tank which was to undergo best management practices as often as opportunities presented. As happened last year, the IRMA has gone on an extended rotation out of the Great Lakes and has not returned since instruments were put in place on April 26, 2005. The remaining six instruments were deployed in the Lady Hamilton on June 3, 2005. For this test we installed 5 instruments in the treatment tank; one in the usual location near the bell mouth and then two pairs placed at the midpoint of the tank with one pair near the outer bilge area and 1 near the center line. For each pair one instrument was placed one inch off the bottom and the second at the top of the tank approximately 2m off the bottom. The objective of these measurements is to examine the patterns of particle concentrations and movement, accumulation/decay of chlorophyll, and patterns of deoxygenation. The instruments will be serviced, including downloading of data, cleaned, and recalibrated during the next voyage into the Great Lakes. A synchronized GPS unit was also installed to give ship position every 15 minutes. These data will be appended to the sonde data.

- On August 17th, the instruments were retrieved from the tanks, data downloaded and the instruments repaired and re-calibrated prior to re-deploying. All of the instruments performed well and have complete data records for the 51 days of record. We did not download the GPS unit at this time since its battery supply is capable of lasting almost 6 months and we were limited in time. Ultimately the GPS log will be time synched with the sonde data to allow for verification of ballast event records kept by the ship and analysis of water quality and sediment dynamics during periods when the ship was ballasting and under voyage in ballast. An example plot of conductivity from one of the instruments is shown in Fig. 1. The plot indicates 3 distinct ballasting operations during this period of record, with fairly different salinities for each ballasting event. The initial spikiness is probably reflective of residual water sloshing back and forth to periodically submerge the sensors.

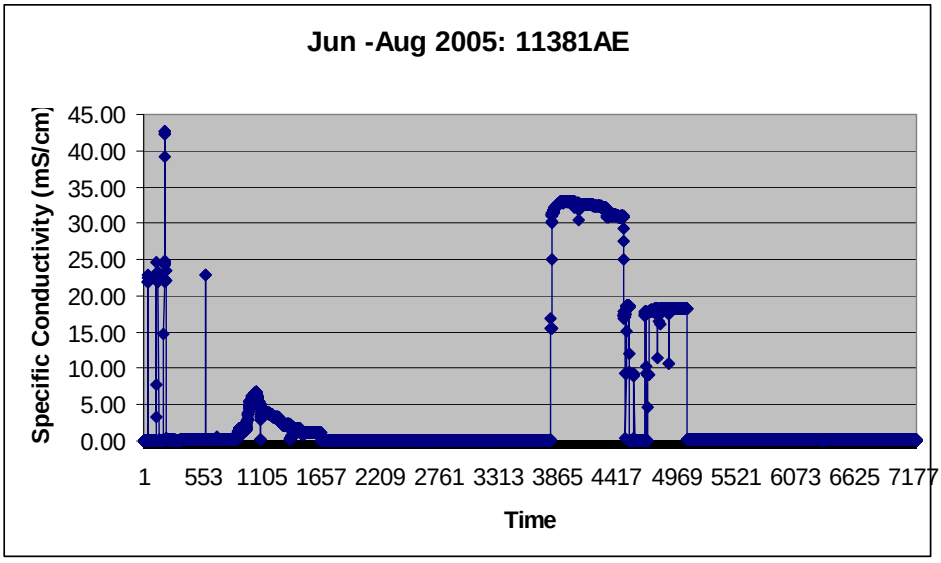


Figure 1. Specific conductivity values during a 51 day deployment within a double bottom tank of the MV Lady Hamilton. Data points represent 15 minute sampling intervals.

In figure 2, we show a time series plot of the dissolved oxygen concentration of ballast water that was collected on July 12 (record 3800) and held for approximately 7.5 days. The oxygen depletion rate was very consistent over time, resulting in a final concentration of less than 1 mg/L. The depletion rate will be a function of both temperature and the amount of organic matter associated with the ballasted water.

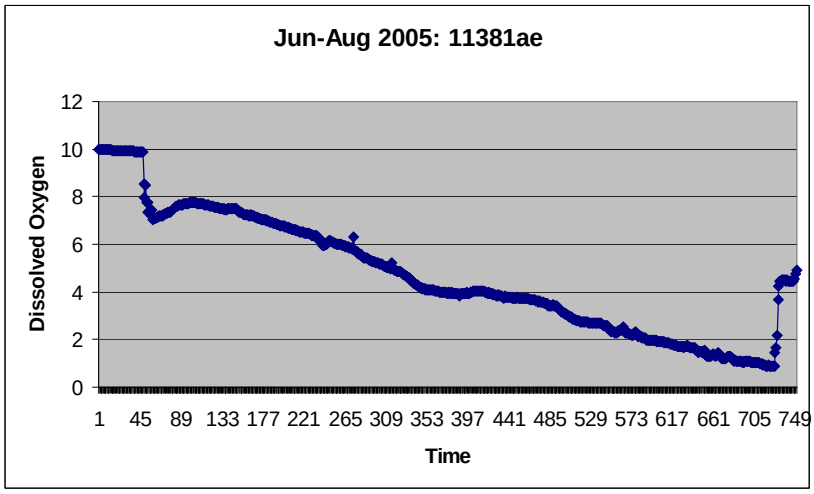


Figure 2. Dissolved oxygen concentrations recording during a ballasted portion of the voyage of the MV Lady Hamilton. The 749 records correspond to a time period of approximately 7.8 days.

Figure 3 shows the same period of record for turbidity, which is a measure of the amount of sediment and plankton suspended in the water. This plot shows high turbidity during the ballasting phase and then a fairly rapid settling of particles over the next 18 hours or so. About the fifth day into the transit particles appear to be resuspending, most likely due to wave conditions and location of the ship on the open ocean. We will have to match up time and position to further understand the results. However, this plot generally supports the notion of both the sediment accumulation process and the opportunity to remove those sediments by resuspending them using an open ocean flushing approach.

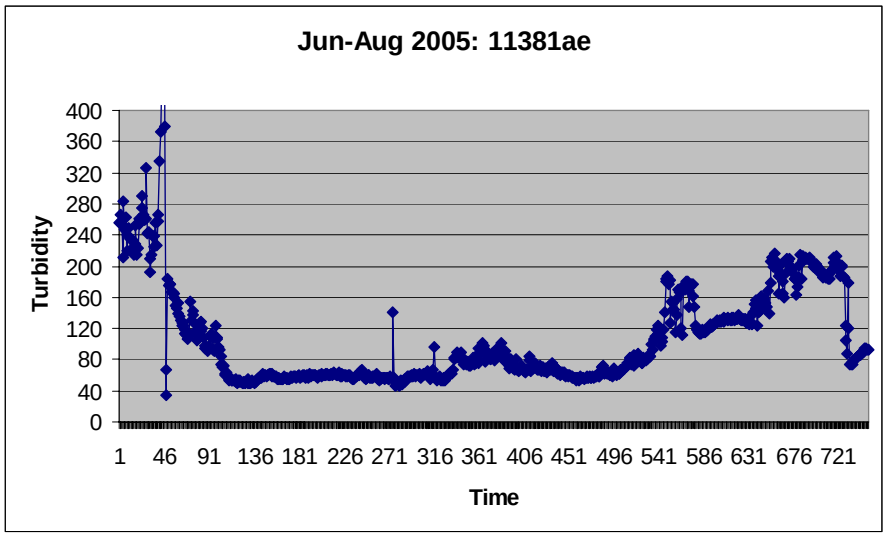


Figure 3. Turbidity values recording during a ballasted portion of the voyage of the MV Lady Hamilton. The 721 records correspond to a time period of approximately 7.8 days.

- It is proving very difficult to accurately measure patterns and amount of sediment accumulation as part of the study. In particular, on the Lady Hamilton there is always 1-2 inches of water covering the floor areas. This water along with the physical structure of the tanks makes it impossible to apply our sediment mapping approach that we initiated based on our experience on the MV/ Irma. Consequently, the instrument data may prove very valuable in helping to analyze sediment conditions in the tanks, particularly in the situation where we are able to deploy multiple (6 or more) sondes. We will also look for other areas of the tank where we may be able to judge/measure whether management practices might be affecting the amount of sediment deposition in the tank.

- To date we have not been able to conduct a direct test of the effectiveness of using any of our recommended enhanced BMPs. While the shipping industry continues to be highly cooperative with us in granting us access to empty ballast tanks and ballasting logs, they have not been willing to modify their commercial operations or ballasting operations in a manner conducive for our project. It is becoming questionable to what extent ships can or will actually apply these 'required' practices in actual operations.

Publications

None to date

Presentations

We have given briefings about the study at several venues including:
Great Lakes Panel on Aquatic Nuisance Species Meeting, Ann Arbor, MI. April 2004.
Water Resources Institute Conference, Michigan State University, E. Lansing, MI. March 2004
Inland Seas Education Association, Invasive Species Field Course, Traverse City, MI. July 2004

Significant Interactions

There have been a number of significant interactions among federal agencies in support of the project.
The USCG and NOAA have provided additional funds to provide additional staff, instrumentation, and travel money. We worked closely with the USCG in developing a workshop on the NOBOB issue.
Chris Wiley from the Department of Fisheries and Oceans in Canada has participated in our field sampling program and has offered to consider supplemental proposals to help extend our project.

Student Participation

Derek Gray, University of Windsor, is using the results of salinity flushing experiments using emergence traps and resting eggs for his Masters thesis. His anticipated completion date is summer 2006.

APPENDICES

Appendix 1 – Count of publications for CILER staff by category.
Appendix 2 – Employee count of CILER staff by Fiscal Year.

APPENDIX 1

Count of Publications

	CILER Lead Author				**NOAA Lead Author**				**Other Lead Author**			
	2001-02	2002-03	2003-04	2004-05	2001-02	2002-03	2003-04	2004-05	2001-02	2002-03	2003-04	2004-05
Peer-Reviewed	10	16	8	7	2	5	2	4	—	—	12	10
Non Peer-Reviewed	1	7	1	2	1	4	6	1	—	—	0	0
TOTAL	11	23	9	9	3	9	8	5	—	—	12	10

APPENDIX 2: Employee Count – from 2001 to 2005, by years

Summary of Joint Institute Staff by Head Count 2001-2002

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	2			2
Visiting Scientists	0			
Postdoctoral Research Fellows	2			2
Research Support Staff	16	10	6	
Administrative	3	1	1	
High School Students	6			
Undergraduate Students	10			
Graduate Students	10			
Totals	49	11	7	4

Summary of Joint Institute Staff by Head Count 2002-2003

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	1			1
Visiting Scientists	0			
Postdoctoral Research Fellows	1			1
Research Support Staff	14	7	6	
Administrative	3	1	1	
High School Students	3			
Undergraduate Students	15			
Graduate Students	6			
Totals	43	8	7	2

Summary of Joint Institute Staff by Head Count 2003-2004

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	0	0	0	0
Visiting Scientists	0	0	0	0
Postdoctoral Research Fellows	0	0	0	0
Research Support Staff	7	3	3	0
Administrative	4	2	1	0
High School Students	3	0	0	0
Undergraduate Students	14	0	0	0
Graduate Students	4	2	2	0
< 50% NOAA Support	14	4	4	3
Totals	46	11	10	3
Located at NOAA Lab	33-GLERL			
Obtained NOAA employment	0			

Summary of Joint Institute Staff by Head Count 2004-2005

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	0	0	0	1
Visiting Scientists	0	0	0	0
Postdoctoral Research Fellows	3	0	0	3
Research Support Staff	7	2	5	0
Administrative	4	2	1	1
High School Students	2	0	0	0
Undergraduate Students	20	0	0	0
Graduate Students	21	13	5	0
< 50% NOAA Support	10	4	4	2
Totals	57	21	15	7
Located at NOAA Lab	41-GLERL			
Obtained NOAA employment	0			